Pipeline Group Factual Report

ATTACHMENT 38

Technical Report OPS 89-11

Carmichael, Mississippi
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TECHNICAL REPORT - OPS 89-1

ELECTRIC RESISTANCE WELD PIPE FAILURES ON HAZARDOUS LIQUID AND GAS TRANSMISSION PIPELINES

AUGUST 1989

Office of Pipeline Safety
Research and Special Programs Administration
U.S. Department of Transportation

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

I. INTRODUCTION

A. Purpose

Following seam failures in 1986 on two hazardous liquid pipelines operated by the Williams Pipe Line Company (Williams) in Minnesota in which two fatalities, one injury, and significant product loss occurred, the Office of Pipeline Safety (OPS) focused attention on the electric resistance weld (ERW) process which had been used in the manufacture of the pipe. Careful metallurgical examination of the failed pipe by OPS, Packer Engineering, and Battelle Columbus Laboratories (Battelle) identified a number of potential problems with the ERW seam welding process that had not been addressed in prior research. The Battelle report prepared for OPS concluded that selective corrosion was the basic cause of this failure. An initial review of Williams' incident reports suggested the possibility that other defects of a near critical size (which could grow under adverse environmental conditions) might exist elsewhere. Prior experience, coupled with the Williams' incident, suggested that the problem might be widespread.

As a result of its evaluation, OPS initiated a review of the quality of some manufacturers' ERW welding processes and the future reliability of pipeline segments containing defective ERW seam welds. This technical report, which is based on the OPS accident information data base and other available information regarding ERW pipe, addresses the safety and reliability of ERW pipe. This report is intended to be a technical report, providing findings on which policy decisions may be determined. For example, the need to require hydrostatic testing of hazardous liquid pipelines, such as ERW, which have not previously been tested, is currently under consideration. During the preparation of this report, the data collected warranted immediate action in the form of an Alert Notice (Appendix D) which OPS sent in January 1988 to all natural gas and hazardous liquid pipeline operators, and a second notice in March 1989.

B. History of ERW Pipe

ERW pipe is manufactured by a process wherein steel strips are continuously welded after being mechanically formed into tubular shapes. As these tubular shapes move through a series of resistance heating and forging operations, a welded seam is produced (Figure 1). The speed of pipe movement through the so-called "fins" or welding and forging heads, the frequency of the current used to heat the pipe, the amount of forging pressure, tolerances on the edges to be joined, and cleanliness are but a few of the critical variables.

The first process for manufacturing ERW pipe was invented in 1929. By 1930 it was being installed as line pipe carrying liquid petroleum, including highly volatile liquids (HVL). Republic Steel had acquired the patent for this process, which used low frequency (about 250 Hertz (Hz)) current to provide heat for fusion of the weld seam. Because of the advantages of using ERW pipe (low basic materials cost, thin and uniform walls, easier handling, and higher pressure rating), demand for ERW pipe grew rapidly.

In order to circumvent Republic's patent rights and enter this rapidly growing market, Lone Star Sheet and Tube of Texas developed a process that used direct current (d.c.) rather than alternating current (a.c.) for seam fusion heat. These two processes, one using a.c. and the other using d.c., were the only ones in early general use. During the period just prior to 1970, a gradual transition to high frequency current for fusion heat, typically at about 450 thousand Hz began. This, together with nondestructive testing (NDT) (e.g., x-ray and ultrasonic testing) placed directly in the production line plus heat treatment of the weld, represented the most significant of many improvements in the manufacture of ERW pipe.

The industry manufacturing specification for higher strength pipe, American Petroleum Institute (API) Specification 5LX included manufacturing standards for ERW pipe in its initial edition in 1947. In the mid 1970s, the API Pipeline Transportation Committee sponsored a research program by Battelle directed toward development of improved tests and procedures for evaluating weld quality in ERW line pipe. Battelle developed a program which resulted in improved ERW weld inspection and bonding characteristics as well as mill test procedures. Later editions of API 5LX (incorporated into API 5L in the early 1980s) introduced these improved manufacturing and testing techniques, providing a significant advancement in ERW pipe quality.

The introduction of federal requirements in 49 CFR Parts 192 and 195, which incorporated API Specification 5LX (now 5L), and subsequent editions, has resulted in a reduction in the number of incidents involving seam splits in ERW pipe.

II. FINDINGS

1. There have been 172 ERW seam failures in hazardous liquid pipelines during 1968-1988 (Table 1) and 103 ERW seam failures in natural gas transmission pipelines during 1970-1988 (Table 6).

2. During the period just prior to 1970, a gradual transition to high frequency current for fusion heat plus other quality control improvements in the manufacture of ERW pipe has led to a decrease in the number of ERW seam failures. This decrease is so significant that it probably cannot be attributed to any other factors than the change to high frequency current and quality control improvements.

3. Ninety-eight percent of the hazardous liquid pipeline ERW seam failures occurred on pipeline constructed prior to 1970 (Table 3). Ninety five percent of the natural gas transmission pipeline ERW seam failures occurred on pipelines constructed prior to 1970 (Table 7).

4. The failure rate of pre-1970 ERW pipelines carrying hazardous liquids is about three times that of pre-1970 ERW pipe carrying natural gas.

5. The two principal causes of hazardous liquid service failures on ERW pipe where a metallurgical analysis has been performed are manufacturing defects or associated specific environmental attack on these manufacturing defects (Table 4). Similar data is not available for gas transmission pipeline failures.

III. ANALYSIS OF INFORMATION

A. Hazardous Liquid Pipelines

A.1 Data Base for Hazardous Liquid Pipeline Incidents

The data base for hazardous liquid pipeline ERW failures used in this report is the OPS liquid pipeline accident data base. This data was obtained using Accident Report - Hazardous Liquid Pipeline - DOT Form 7000-1 (OMB No. 2137-0047). The data in the accident report form was revised in 1985, but the form number was not changed. In accordance with §195.50, these reports must be submitted to DOT if there is a release of the hazardous liquid transported resulting in any of the following:

(a) Explosion or fire not intentionally set by the operator.
(b) Loss of 50 or more barrels of liquid.
(c) Escape to the atmosphere of more than five barrels a day of highly volatile liquids.
(d) Death of any person.
(e) Bodily harm to any person resulting in one or more of the following:
(1) Loss of consciousness.
(2) Necessity to carry the person from the scene.
(3) Necessity for medical treatment.
(4) Disability which prevents the discharge of normal duties or the pursuit of normal activities beyond the day of the accident.
(f) Estimate property damage to the property of the operator or others, or both, exceeding $5,000.

Part C of the above referenced form, "Origin of Liquid or Vapor Release," contains 14 specific leak sources, one of which, the "longitudinal weld," was the characteristic denoting a seam failure. In most cases, it could only be inferred that the seam was an ERW seam since there were no requirements to identify the seam weld type. Since the bulk of the pipe mills were producing only ERW pipe during this period, this is not an unreasonable assumption.

Data collected by the OPS staff during the 1968-1977 time period was consolidated on an annual basis and presented in a report entitled "Summary of Liquid Pipeline Accidents, 1968-1977" and that data was used in this report. The data used in this "Summary of Liquid Pipeline Accidents, 1968-1977" was verified by discussing each failure with operators to make sure that the failure was in an ERW seam. OPS records do not include metallurgical reports for this period 1968-1977 for liquid pipeline accidents. Eighteen metallurgical reports (where available) describe the cause of failure for liquid pipeline accidents from 1979 to 1987. These reports are summarized in Appendix A - "Metallurgical Examination of Failures."

In addition to the data from individual accident reports, data from the following sources was used in developing this report:

- "Summary of Liquid Pipeline Accidents, 1968-1977" (OPS internal report).

° OPS records of individual operator reports of accidents due to seam failure (retrieval of attributes, "Longitudinal weld" as leak source, and "Defective weld" as failure cause).

° NTSB accident reports.

° 1984 OPS "Annual Report on Pipeline Safety."

° "Liquid Petroleum Pipeline Accident Report" (Lakehead Pipeline Company consolidation of all individual accident reports, 1985).

A.2 Analysis of the Data

A.2.1 Failures of ERW seams in liquid pipelines

Table 1 presents a summary of 172 failures in ERW seams for pipelines carrying hazardous liquids during the period 1968-1988. The table presents data relevant to the cause of the ERW seam failure where it was reported on the incident forms or available as a result of follow-up failure analyses initiated by the operator. The data presented represent service failures unless the failure date matches the hydrostatic pressure test date. Table 2 presents a summary of seam failures by hydrostatic testing of a Mid-America Pipeline Company pipeline system from Cherokee County, Iowa, to Blue Earth County, Minnesota.

Table 3 presents a summary of ERW seam failures from 1968 to 1988 in hazardous liquid pipelines by construction decade. This table shows that 98 percent of the failures occurred on pipe manufactured prior to the 1970s. The data presented in Figure 2 illustrates the decreasing trend in the number of ERW seam failures for liquid pipelines.

The failures which were documented by metallurgical testing and evaluation proved to be largely due to manufacturing defects in the seam. The causes of failures based on metallurgical examinations of 58 service failures or hydrostatic test failures in the ERW seams of hazardous liquid pipelines between 1977-1988 are summarized in Table 4. Lack of fusion defects open to the outside diameter accounted for 52 percent of the failures. Selective corrosion failures accounted for about 10 percent of the failures while fatigue cracks initiating from discontinuities, such as pipe wall edge mismatch (high/low) or hard spots, accounted for about 10 percent of the defects. Hook cracks accounted for about 6 percent of the defects and the balance of failures was attributable to defects not related to the ERW process, such as laminations or arc burns. A description of each type of defect is provided in Appendix C.

Table 5 illustrates the number of service and hydrostatic test failures by manufacturer for the 1977-1988 reporting period. There is no data in the OPS pipeline data base to determine the total mileage of ERW pipe in the country or the mileage by manufacturer. Therefore, it is not possible to compare the failure rate (i.e., the failures per mile) of different manufacturers of pipe.

The API published data in a 1987 research report which indicated that about 46,000 miles or 41 percent of all hazardous liquid pipeline is ERW pipe made before 1970, approximately 20,000 miles, or 17 percent, is ERW pipe made after 1970. Therefore, of all hazardous liquid pipeline, about 58 percent is ERW pipe. According to that report, the balance of the liquid pipeline is: 23.5 percent - seamless; 10.3 percent - submerged arc welded pipe; 3 percent - lap welded; and 5 percent - unspecified.

Figure 2 illustrates the decline in number of hazardous liquid pipeline seam failures of all kinds from 1968 to 1986. Also illustrated is the number of ERW seam failures during the same period. Some studies indicate that while the overall rate of failures of all seams, including ERW pipe, is decreasing, the relative rate of failure of pre-1970 ERW pipe to that of all seam failures has been increasing since 1978.

A.2.2 Relationship between service failures and hydrostatic testing

The service failures summarized in Table 1 were examined to determine the time interval between the failure and the most recent hydrostatic test, if tested. Approximately 26 percent of the service failures occurred on pipelines which had not been previously hydrostatically tested. Approximately 27 percent of the service failures occurred on pipelines where the ratio of hydrostatic test pressure to service failure pressure was less than 1.25 (ratios at or above 1.25 are required by regulation for liquid pipelines constructed after 1971) and the average time interval between the service failure and most recent hydrostatic test was about 16 years. About 47 percent of the service failures occurred on pipelines where the ratio of hydrostatic test pressure to service failure pressure was more than 1.25 and the average time interval between the service failure and most recent hydrostatic test was about 15 years.

B. Natural Gas Pipelines

B.1 Data Base for Natural Gas Pipeline Incidents

Data on natural gas pipeline ERW failures was obtained from the OPS natural gas pipeline incident data base. This data base was based on operator reports using the RSPA Incident Report - Gas Transmission and Gathering Systems, RSPA F7100.2 (3-84) (OMB No. 2137-0522). This current form was put into use in early 1984 and is submitted to OPS within 30 days of the occurrence of an incident. In changes made to 49 CFR §191.5 in 1984 an incident was defined to include any of the following events:

(1) An event that involves a release of gas from a pipeline or liquefied natural gas or gas from an LNG facility and

(i) A death or personal injury necessitating in-patient hospitalization, or

(ii) Estimated property damage, including cost of gas lost, of the operator or others, or both, of $50,000 or more.

(2) An event that results in an emergency shutdown of an LNG facility.

(3) An event that is significant, in the judgment of the operator, even though it did not meet the criteria of paragraphs (1) or (2).

Before 1984, incidents were reported on a longer, more extensive form, DOT F7100.2 (1-70) (Budget Bureau No. 04-R5605). In addition, before 1984 an incident that required the submission of a report form was defined to include any of the following events:

(1) Caused a death or a personal injury requiring hospitalization;

(2) Required the taking of any segment of transmission pipeline out of service;

(3) Resulted in gas igniting;

(4) Caused estimated damage to the property of the operator, or others, or both, of a total of $5,000 or more;

(5) In the judgment of the operator, was significant even though it did not meet the criteria of paragraphs (1), (2), (3), or (4);

(6) A leak in a transmission line that required immediate repair; or

(7) A test failure that occurred while testing either with gas or another test medium.

B.2 Analysis of the Data

B.2.1 Failures of ERW seams in natural gas transmission pipelines

The data collected from the RSPA Incident Reports - Gas Transmission and Gathering Systems, RSPA forms F7100.2 (1-70 and 3-84) is summarized in Table 6, "Summary of ERW Seam Failures in Gas Transmission Pipelines," showing 103 failures during the period 1970-1988. A graph of the number of ERW seam failures in hazardous liquid and natural gas transmission lines by year of occurrence is shown in Figure 3. The data for both natural gas and hazardous liquid lines illustrates a common trend; that of a generally decreasing number of incidents by year. Table 7 illustrates that about 95 percent of the ERW seam failures occurred on pipelines constructed prior to 1970.

Generally, the data available from RSPA F7100.2 were not specific with regard to the causes of ERW seam splits in Table 6. From the three incidents which are described in metallurgical reports selective corrosion of the ERW seam was cited as the cause of failure in two cases. In the third, cracks at a hard spot were cited as the cause of the seam split. It is believed that Table 4, "Cause of Failures of ERW Seams - Hazardous Liquid Pipelines," is representative of the failures in ERW seams for natural gas transmission pipelines for two reasons:

(1) Both sets of data represent the same type of ERW pipe manufactured by generally the same type of ERW pipe mills for the same period of time.

(2) The nature of ERW seam splits is unlikely to be different for different commodities since the splits are generally known to be caused by manufacturing defects or associated specific environmental attack on these manufacturing defects. In none of the incidents reviewed was internal (selective) corrosion involved which might be influenced by the contents of the pipe (such as CO_2, sour gas, or gas containing corrosive liquids and distillates or condensates).

The data presented in Table 8, "ERW Failure Distribution by Manufacturer - Natural Gas Transmission Pipelines," for the period 1970-1988. As in Table 5, the data is not normalized with respect to mileage of pipe produced.

B.2.2 Relationship between service failures and hydrostatic testing

Hazardous liquid pipeline failures were analyzed in A.2.2 to determine if the ratio of hydrostatic test pressure to service failure pressure was less than 1.25. For hazardous liquid pipelines constructed after January 8, 1971, this ratio represents the minimum spread allowed between test pressure and maximum operating pressure. A similar analysis is not possible for gas transmission lines because under the gas pipeline regulations the minimum spread between test pressure and maximum operating pressure varies with initial class location (population density) and subsequent changes in class location. The DOT failure data do not indicate whether the class location of a failed pipeline is an initial or changed classification. Also, class location data are only in the new incident reporting form, which was published in 1984, and only 12 out of 103 ERW gas failures have occurred since the new report form was published.

A major difference between the gas and hazardous liquid pipeline regulations is that operators must hydrostatically test gas transmission pipelines or reduce their maximum operating pressure when significant increases in population occur near the pipelines. This difference results in gas transmission lines being hydrostatically tested much more often than hazardous liquid pipelines.

The service failures occurring on ERW seams for natural gas transmission pipelines (summarized in Table 6) were examined to determine the time interval between the service failure and the most recent hydrostatic test, if tested. The average time interval between the service incident and the most recent hydrotest was found to be about 17 years.

C. <u>Relative failure rate of pre-1970 ERW pipelines carrying hazardous liquids and pre-1970 ERW pipelines carrying natural gas</u>

The DOT pipeline user fee account summary reflects the total hazardous liquid transmission pipeline mileage as 154,000 and a total of 292,000 miles of natural gas transmission pipelines. In order to compare the pre-1970 ERW seam failures for hazardous liquid pipelines and natural gas transmission pipelines, it was assumed that the relative percentage of pipelines with ERW seams was the same for both, since similar pipe was in common use at that time by gas and hazardous liquid pipeline operators. Based on this assumption, the 173 hazardous liquid pipeline failures in Table 1 and the 103 natural gas transmission failures in Table 6, the ratio of ERW failures per mile is about 3:1 for hazardous liquid vs. natural gas transmission pipelines.

TABLE 1

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA.	WALL	GRADE	CAUSE OF FAILURE
Phillips			1700	08-68	1947				5LX42	Split (seam)
Phillips			600	05-68	1930-1935				GrB	Corrosion (seam) - defective pipe
Hydrocarbon Transmission	1690		1000	01-68	1963		8 x	.219	5LX-42	L.O.F. ERW seam
Pure Trans. Co.	750		430	06-68	1937		10 x	.307		ERW seam opened 61-inch, seam area corrosion
Continental	1203		670	10-68	1959		6 x	.156	5LX-42	Defective longitudinal weld, split seam
Phillips			1175	09-68	1951		12 x	.250	IIIIE 45	Defective longitudinal weld, fusion defect
Phillips	1350		1140	05-68	1951		10 x	.203	5LX-42	Defective longitudinal weld, rupture
Mid-America	1628		1525	12-68	1960		8 x	.219	5LX-52	Defective longitudinal weld, cold weld ERW
Continental	2331		1560	03-68	1961		8 x	.219	5LX-52	Defective pipe, longitudinal weld, 8-foot split in weld
Continental	1942		1695	05-68	1961		8 x	.219	5LX-52	Defective pipe
Continental	1300		1020	06-68	1961		8 x	.156	5LX-52	Defective pipe, 4-foot split
Continental	1927		1375	11-68	1961		8 x	.188	5LX-52	Defective longitudinal weld, 14-inch split, partial weld
Platte	1000		1000	09-68	1952		20 x	.344	5LX-52	4-foot split longitudinal weld, incomplete penetration
Platte	1000		1230	03-68	1952		20 x	.312	5LX-52	33-foot split
Wabash	1440		1000	10-68	1946		12 x	.250	5LX-46	Seam split, not completely welded
Gulf Refining			400	02-68	1920s				GrB	Seam ERW, defective pipe
Continental	720		450	02-68	1966		4 x	.109	5LX-52	Defective longitudinal weld
Kaneb	1500		1200	04-68	1964		6 x	.156	5LX-42	Defective pipe, longitudianl weld, 64-feet replaced
Jayhawk			1300	12-68	1967		6 x	.156	5LX-42	Defective pipe, longitudinal weld,

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. x WALL	GRADE	CAUSE OF FAILURE
Mid-America	1650		1500	10-68	1960		8 x .219	5LX-52	Faulty longitudinal weld
Lakehead	859			12-68	1954			5LX-52	Rupture longitudinal weld
Williams	1100		900	10-68	1930-1935		8 x .290	GrB	
Williams	1390		1400	02-68	1950		12 x .250	5LX-42	
Williams	1550		1630	12-68	1957		8 x .125	5LX-42	Defective weld
Continental	1800	1961	1200	02-69	1961		6 x .156	5LX-52	Defective pipe, longitudinal weld, 3-foot split seam
Continental	1927	1961	1050	09-69	1961		8 x .188	5LX-52	Defective pipe, split down the seam
Continental	1927	1961	1200	11-69	1961		8 x .188	5LX-52	Defective pipe, 3-foot split along longitudinal weld
Continental	840	1965	680	12-69	1965		6 x .188	GrB	Defective pipe, longitudinal weld, replace 10-feet of pipe
Jayhawk			<1145	12-69	1967		6 x .156	5LX-42	Defective pipe, longitudinal weld ruptured
Lakehead	860	1965		04-69	1957		26 x .281	5LX-52	Defective weld, 1-inch hairline crack longitudinal seam
Mid-America	1655	1960	1518	02-69	1960		8 x .219	5LX-52	Defective pipe, longitudinal weld, defective longitudinal weld ruptured
Mid-America	1685	1960	1540	12-69	1960		8 x .219	5LX-52	Defective pipe, longitudinal weld, seam partially fused
Phillips			920	01-69	1930-1935		8 x .277	GrB	Defective pipe, longitudinal weld, defective seams
Phillips			678	03-69	1951		8 x .188	5LX-42	Defective pipe, longitudinal weld, ERW cold stitch, crevice corrosion
Phillips	Air-100 Oil-1400	1948	956	06-69	1948		12 x .250	IIIIE 45	Defective pipe, longitudinal weld, ruptured in normal operation
Phillips			900	10-69	1942		8 x .188	MB 40	Defective weld, longitudinal weld, split 23-inch in normal operation
Phillips			785	11-69	1942		8 x .188	MB 40	Defective weld, longitudinal weld,

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. x WALL	GRADE	CAUSE OF FAILURE
Plantation	1380	1964	1300	06-69	1964		14 x .219	5LX-52	Longitudinal weld, split 54-inch ERW
Pure Transp. Co.	750	1960	460	08-69	1937	Repb.	10 x .307		Defective pipe, longitudinal weld, split 24-inch
Southern Pacific	1990	1955	1350	07-69	1955		8 x 7/32		Defective pipe, longitudinal weld, 39-inch split, replace 33 feet
Continental	1000	1968	550	09-69	1953		2 x .125	GrA	Defective weld, line split in weld, 1,000 barrel spill
West Shore	1760	1961	1300	06-69	1961		10 x .203	5LX-52	Defective pipe, longitudinal weld, failure along seam
Mid-America	1786		1100	11-70	1969		8 x .156	5LX-52	Defective pipe, 20-inch split, longitudinal crack
Shell	1100		1200	04-70	1956		6 x .188	GrB	Longitudinal weld
Phillips	1200		942	12-70	1930-1935		8 x .277	GrA	Factory seam, ERW pipe
Inland Corp.	850		850	06-70	1943			GrB	ERW split
Inland Corp.	850		850	06-70	1943			GrB	ERW, 3-foot split
Emerald	1500		850	07-70	1954			GrB	Defective pipe, seam split
Amoco			1300	01-70	1953		12 x .312	5LX-42	Defective pipe, failure adjacent to longitudinal weld
Continental			1200	09-70	1938		4 x .237	GrB	Defective seam, rupture by blown seam
Phillips	1250		885	12-70	1942	Repb.	8 x .188		ERW, factory defect, 7-foot split in seam
Phillips			920	01-70	1930-1935			GrB	Longitudinal weld defect
Humble			200	01-70	1956		12 x .312	GrB	Rupture, defective weld
Platte	1000		1040	06-70	1952	Kais. Elco		5LX-52	50 percent penetration (L.O.F.)
West Shore	1760		1360	07-70	1961		10 x .203	5LX-52	Defective pipe, failure longitudinal seam

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS
1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Williams				11-70	1950		12 x .250 5LX-42	26-inch lamination along longitudinal seam
Chevron	2325		1750	12-70	1952		8 x .277 5LX-42	ERW, defective pipe, seam lamination, 1/2-inch wall weld
West Shore	1760		1200	12-70	1961		10 x .203 5LX-52	Split longitudinal weld, ERW
Continental	2170	1961	1675	02-71	1961		8 x .250 5LX-52	Defective weld, 41-foot split longitudinal weld, full joint
Continental	1440	1961	1100	05-71	1961		8 x .156 5LX-52	ERW, defective pipe, 3-foot split, cold stitch, corrosion in seam
Continental	2170	1961	1690	08-71	1961		8 x .250 5LX-52	ERW, 6-foot split
Continental	2040	1961	1250	11-71	1961		8 x .188 5LX-52	Defective longitudinal weld, 3-foot split
Continental	2375	1961	1610	12-71	1961		8 x .219 5LX-52	Defective weld, split longitudinal weld, replace joint
Continental	2251	1969	1105	12-71	1961		8 x .188 5LX-52	Defective weld, split longitudinal weld of joint
Continental	2720	1961	1160	12-71	1961		8 x .250 5LX-52	Defective weld, split in longitudinal weld
Hess	1200	1963	250	01-71	1963		8 x .188 5LX-52	Defective pipe, split at very low pressure
Mapco	1609	1960	1550	02-71	1960		8 x .219 5LX-52	Defective pipe, split longitudinal seam
Phillips	1400	1948	965	08-71	1948		12 x .250 IIIIE 45	Defective weld, faulty seam caused leak
Phillips			1002	04-71	1948		12 x .250 IIIIE 45	Defective weld
Yellowstone	1850	1954	1361	07-71	1954		10 x .250 5LX-46	Defective weld, 48-inch split longitudinal weld, part fusion
Wabash	1440	1963	1265	07-71	1958		12 x .250 5LX-46	Defective pipe, replaced entire joint that had split

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS
1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Continental	1650	1961	1560	02-72	1961		8 x .219 5LX-52	Split in defective longitudinal weld
Continental	2243	1968	1520	07-72	1968		12 x .250 5LX-60	Split in defective longitudinal weld
Humble	1380	1966	1020	01-72	1966		16 x .219 5LX-56	Longitudinal split, faulty weld
Lakehead	773	1964	540	07-72	1954		30 x 5/16 5LX-52	2-foot split, longitudinal weld
Lakehead	890	1965	414	03-72	1956		26 x .281 5LX-52	Defective longitudinal weld
Lakehead	814	1965	510	07-72	1957		26 x .281 5LX-52	4-inch crack, defective longitudinal weld
Phillips	1400	1949	950	07-72	1948		12 x .250 IIIIE 45	Split defective weld seam
Phillips	2000	1947	1845	08-72	1947		6 x .188 5LX-42	Defective longitudinal weld
Phillips	1400	1949	1120	10-72	1948		12 x .250 IIIIE 45	Split caused by defects, weld seam
Platte			1200	05-72	1954		20 x .344 5LX-52	Defective pipe failed below 72 percent SMYS
Platte	1200	1952	1080	07-72	1951		16 x .281 5LX-52	Pipe split
Shell			400	01-72	1940		6 x .169 GrB	Defective pipe, design
Texas-NM	1125	1958	745	10-72	1957		16 x .250 5LX-46	Defective longitudinal weld, 26-foot long rupture
Williams			1267	07-72	1955		10 x .203 5LX-46	Defective pipe, longitudinal weld failed
Continental	1570	1972	1168	08-73	1961		8 x .188 5LX-52	4-foot split in defective longitudinal weld
Gulf Refining			840	10-73	1942		8 x .322	Line split, ERW
Mobil	1039	1968	935	08-73	1948		12 x .250 GrB	ERW seam failed at 4-inch stitch, total split 35 feet
Phillips	1400	1949	1050	05-73	1949		12 x .250 IIIIE 45	Defective weld, longitudinal seam, split 4 feet
Texas	1000	1948	905	12-73	1948		20 x .344 5LX-46	Defective pipe, split 15 feet in seam

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Williams			1116	03-73	1950		12 x .250 5LX-42	ERW seam split, appears laminated
Yellowstone	1850	1954	1548	05-73	1954		10 x .307 5LX-46	Defective longitudinal weld, split 50 feet
Continental	1967	1972	1507	01-74	1961		8 x .219 5LX-52	Defective longitudinal weld
Continental	1967	1972	1642	01-74	1961		8 x .219 5LX-52	Defective longitudinal weld
Continental	1967	1972	1494	05-74	1961		8 x .219 5LX-52	Defective weld, joint replaced
Marathon	1000		700	06-74	1949		22 x .344 5LX-46	Defective pipe seam split, 42 foot
Platte	1000	1954	107	02-74	1954		20 x .344 5LX-52	Defective longitudinal weld, 4-foot split in seam
Texas	1000	1949	990	03-74	1949		12 x .281 5LX-42	Defective ERW, longitudinal weld
Williams			748	03-74	1950	Repb.	12 x .250 5LX-42	Defective ERW, seam opened
Williams			1010	03-74	1946		8 x .203 GrB	Defective pipe, longitudinal weld, seam opened
MAPCO	1840	1973	700	05-74	1973		4 x .125 GrB	Weld seam split in ERW pipe
Phillips	1400		1004	03-75	1948		12 x .250 IIIIE 45	Defective longitudinal weld, seam failed
Mid-America	1652		1346	05-75	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld, 25-foot rupture
Mid-America	2061			07-75	1970		4 x .125 5LX-42	Defective pipe, longitudinal weld, 14-inch seam rupture
Mid-America	1600		1300	07-75	1960		4 x .142 5LX-42	Weak seam section blew out
Mid-America	1662		1265	08-75	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld, 25-inch split
Marathon	1625		1275	10-75	1957		12 x .250 5LX-46	Defective pipe, longitudinal weld
Mid-America	1652		1470	11-75	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld
Amoco	1150		820	12-75	1962		18 x .219 5LX-52	Defective pipe, longitudinal weld, 4-foot split

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Mid-America	1598		1345	01-76	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld, split
Mid-America	1660		1550	02-76	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld, stitched, ERW
Mobil	1087		820	03-76	1947		12 x .250 GrB	Defective pipe, longitudinal seam, hook cracks
Powder River			1885	06-76	1947		6 x .188 5LX-42	Defective pipe, longitudianl seam
Phillips	100		810	07-76	1951		12 x .250 EW 45M	Defective pipe, 37-inch split
Husky	1240		1210	07-76	1960		6 x .156 5LX-42	Defective pipe, replace 54 feet
Mid-America	1645		1293	08-76	1960		8 x .219 5LX-52	Defective pipe, longitudinal weld
Colonial	1440		1234	08-76	1963		12 x .219 5LX-52	Defective pipe, longitudinal weld, split seam
Phillips	100		733	10-76	1952		12 x .250 IIIIE 45	Defective pipe, longitudinal weld, seam failed
Williams			1166	12-76	1950		12 x .250 5LX-42	Defective pipe, longitudinal seam, split 5 foot, ERW
Mobil	1135		952	12-76	1955		16 x .250 5LX-46	Defective pipe, faulty longitudinal seam, ERW split open 56 inches
Phillips	100	1951	755	01-21-77	1951		12 3/4 x .250 IIIIE 45	Defective pipe, 34-inch long split
Continental			650	01-24-77	1938		4 x .237 GrB	
Williams			1150	04-09-77	1950		12 x .250 5LX-42	Defective pipe, longitudinal weld
Exxon	1200	1968	1040	04-22-77	1960		16 x .250 5LX-52	Defective pipe, longitudinal weld
Sun			575	06-30-77	1942		7 x .344 GrB	
Phillips	1400		1310	08-11-77	1948		12 3/4 x .250 IIIIE 45	
Phillips	100	1954	600	08-19-77	1954		4 1/2 x .188	
Powder River	2000	1951	1540	09-28-77	1951		6 x .188 5LX-42	Defective pipe

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Minnesota	1390	1955	940	11-04-77	1955		16 x .250 5LX-52	
Warren	1400	1957	800	12-01-77	1957		4 1/2 x .156 GrB	
Marathon			850	12-13-77	1930-1935		8 x .322 GrB	
Mid-Valley	1100	1950	750	01-02-78	1950			
Continental	1927	1961	835	03-16-78	1961			
Minnesota	1350	1955	1000	01-18-78	1954			
Williams	1465	1970	1187	03-23-79	1970		16 x .250 5LX-52	
Colonial	730	1963	580	05-13-79	1963	U.S. Steel		
Ozark	1000	1949	726	08-24-79	1949	Ygtn.	22 x .344 5LX-46	Outside force
Exxon	1200	1957		05-04-79	1950		18 x .281 5LX-45	L.O.F., outside - selective corrosion
Gulf Refining			250	02-07-79	1953		10 3/4 x .365 GrB	
Minnesota	1420	1955	690	01-11-80	1954	Ygtn.	16 x .250 5LX-52	I.D. L.O.F. and hook crack on O.D. 10-inch long defect X 0.5 a/w
Continental	2110	1968	1750	10-24-80	1968		12 x .250 5LX-60	
Lakehead	705	1963	600	05-26-80	1963	U.S. Steel	34 x .281 5LX-52	Hook cracks, enlarged by environmental cracking/corrosion fatigue, overpressure
Lakehead	947	1974	724	12-19-81	1956		26 x .281 5LX-52	
Williams		1968	1340	02-11-81	1968		12 x .250 5LX-52	
Southern Pacific	2550	1955	1460	02-01-82	1955		12 x .375 5LX-46	
Capline	1100	1974	430	09-13-82	1974		22 x .312 5LX-52	
Colonial	1440	1963	1216	08-16-82	1963		12 x .219 5LX-52	
Texas Eastern	350	1957	200	12-07-83	1957		16 x .375 GrB	
Williams			1586	12-09-83	1957	J&L	8 5/8 x .250 5LX-42	Hook cracks, opened seam during overpressure on No. 2-8 line

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. WALL GRADE	CAUSE OF FAILURE
Williams			1136	08-19-83	1950		12 x .250 5LX-42	L.O.F. on O.D.
Texas Pipeline	1000	1948	939	10-10-84	1948			
Sun			786	06-14-84	1930-1935		10 x .307 GrB	
Southern Pacific	1715	1955	630	03-21-84	1955		12 x .250 5LX-46	Selective seam corrosion
Minnesota	1468	1980	1100	02-11-84	1954	Ygtn.	16 x .250 5LX-52	Fatigue at 18-inch long lamination at one edge of plate on ERW weld
Williams			1014	11-16-84	1955	J&L	8 5/8 x .250 5LX-42	L.O.F. on outside of No. 2-8 line
Continental	2118	1968	1500	08-18-85			12 x .250 5LX-60	
Williams			1428	05-19-86		J&L	8 5/8 x .250 5LX-42	L.O.F. on outside of No.2-8 line
Williams	1900	1984	1434	07-08-86	1957	J&L	8 5/8 x .250 5LX-42	Selective seam corrosion on outside of No. 2-8 line
San Diego	1979	1963	1466	11-22-86	1962	Kais.	10 x .219 5LX-52	Internal corrosion fatigue at L.O.F. penetrator
Lakehead	810	1975	642	10-02-86	1967		34 x .281 5LX-52	1/2-inch O.D. L.O.F., 100 percent WT
Portal	1268	1965		03-20-86	1965		6 5/8 x .125 5LX-42	
Marathon	1622	1974	1295	01-07-86			12 x .250 5LX-46	
Williams	1900	1986	1900	(09-86)	1957	J&L		Seven seam splits in L.O.F. penetrators on No.2-8 line
Williams	1903-1930	1986	1903-1930	(09-86)	1957	J&L		Three seam splits on outside L.O.F. penetrators on No. 1-8 line
Continental			1632	03-31-87	1962	Repb.	8 5/8 x .188 5LX-52	Severe selective corrosion nearly penetrating pipe wall due to inadequate cathodic protection
Plantation			1100	05-07-87	1964	Bthlm	12 3/4 x .203 5LX-52	Failure at midwall lamination, elongated manganese sulfide inclusion
Williams			970	06-12-87	1946	Repb.	8 5/8 x .188 GrB	Fatigue crack initiating at internal high/low Alexandria-Grand Forks No. 1-6 line

TABLE 1 (continued)

SUMMARY OF FAILURES IN HAZARDOUS LIQUID PIPELINES IN ERW SEAMS 1968 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TEST DATE	FAILURE PRESSURE	FAILURE DATE	INST.	MFGR.	PIPELINE DATA DIA. x WALL	GRADE	CAUSE OF FAILURE
Williams	1241	1987			1946	Repb.	8 5/8 x .250	5LX-42	Leak internal L.O.F. open to O.D.
Williams	1499	1987				Repb.	8 5/8 x .250	5LX-42	Rupture at weakly fused center zone ERW seam 3.0-inch long
Williams	1241	1987			1946	Repb.	8 5/8 x .250	5LX-42	Leak internal L.O.F. open to O.D.
Williams	1508	1987			1946	Repb.	8 5/8 x .250	5LX-42	Leak internal L.O.F. open to O.D.
Williams	1385	1987			1946	Repb.	8 5/8 x .250	5LX-42	Rupture O.D. hook crack with possible internal corrosion
Mid-America	1830	1960	1550	04-16-87	1960	Ygtn.	8 5/8 x .219	5LX-52	Hydrogen stress cracking at hard seam
Yellowstone Pipeline Co.		1954	1684	06-03-87	1954		10 x .250	X46	Seam split
So. Pacific Pipeline Co.	1800	1963	610	06-29-87	1963		8 5/8 x .188	X46	1 1/2-inch seam crack
Conoco	2100	1963	1454	10-26-87	1963		8 5/8 x .188	X52	
MAPCO	1726 2188	1960 1976	1468	07-22-88	1960	Natl. Tube	8 5/8 x .219	X52	Selective corrosion
So. Carolina Pipeline Co.	1019	1958	747	01-25-88	1958		12 3/4 x .250	B	Selective corrosion
Conoco	2560	1961	1541	01-21-88	1961		8 5/8 x .219	X52	Selective corrosion
Williams				Five failures		J&L	6 5/8 x .188	B	Hook crack
Phillips	1825	1981	860	04-02-88	1951		6 5/8 x .188	X42	Pinhole in seam
Lakehead	853	1964	543	05-23-88	1953		30 x .343	X52	3/4-inch seam crack
Minnesota	1528	1980	1020	12-01-88		Ygtn.	16 x .250	X52	Lamination at seam
Shell	1000 (design MOP = 1035)	1949	910	12-24-88	1949	Ygtn.	22 x .344	X46	Hook crack in ERW seam

TABLE 2

MID-AMERICA PIPELINE COMPANY
HAZARDOUS LIQUID PIPELINES
SEAM FAILURES DURING HYDROTESTING
(1987)

FAILURE NUMBER	MANUFACTURER	FAILURE PRESSURE	DATE	DESCRIPTION OF FAILURE ORIGIN
1	2.0	2520	——	L.O.F. defect with no defined origin
2	2.0	2420	——	4-inch long L.O.F. defect full wall at girth weld
*3	2.0	——	——	
4	2.0	Leak	5-23-87	Leak 9/16-inch long on outside and 7/16-inch long on inside L.O.F.
*5	2.0	——	——	
6	2.0	Leak	6-28-87	Leak 1/8-inch long on outside and 3/16-long on inside L.O.F.
7	2.0	2014	6-29-87	Inside L.O.F. 13-inch long and from 10 percent to 80 percent of wall thickness
8	2.0	Leak	——	Leak 1/4-inch long on outside and 1/8-inch long on inside
9	2.0	1910	7-11-87	L.O.F. on outside 2 3/4-inch long and 50 percent of wall thickness
10	3.0	2542	7-11-87	L.O.F. of undetermined dimension
11	2.0	2580	7-11-87	L.O.F. on outside 3-inch long and 3/16-inch deep (85 percent of wall thickness)
12	3.0	2580	7-13-87	L.O.F. - no obvious dimensions
13	2.0	2083	7-13-87	L.O.F. on outside, 6-inch long and 30 percent of wall thickness
14	3.0	2580	7-14-87	L.O.F. on inside, 4-inch long and 50 percent of wall thickness
15	2.0	2101	7-14-87	L.O.F. on outside, 6 1/2-inch long and 57 percent of wall thickness
16	3.0	2560	7-15-87	L.O.F. on outside, 5 3/4-inch long and 20 percent of wall thickness
17	2.0	2543	7-16-87	Leak - no obvious origin, 7/16-inch long on outside and 3/8 inch on inside
18	2.0	2242	7-16-87	L.O.F. on outside, 7-inch long and 85 percent of wall thickness
19	3.0	2213	7-20-87	L.O.F. on inside, 4-inch long and 57 percent of wall thickness
20	2.0	2572	7-21-87	Origin at hard spot
21	2.0	2574	7-21-87	L.O.F. at outside 8-inch long and 85 percent of wall thickness
22	2.0	2260	7-23-87	

1.0 - All pipe was 8 5/8 x 0.219 ERW API 5LX-52 - manufactured by Youngstown or Lone Star
2.0 - Youngstown Sheet & Tube(15)
3.0 - Lone Star(5)
* - Girth weld leak

TABLE 3

ERW SEAM FAILURES IN HAZARDOUS LIQUID PIPELINES
CONSTRUCTION DECADE DISTRIBUTION
1968 - 1988

Event Year	CONSTRUCTION DECADE 1920s	1930s	1940s	1950s	1960s	1970s	1980s	Unk.	Totals
1968	1	4	1	8	10				24
1969	1	3	3	2	9				18
1970		3	3	7	3				16
1971			1	3	9				13
1972			1	10	3				14
1973		1	2	2	2				7
1974			3	2	4				9
1975			1	1	5	1			8
1976			2	4	5				11
1977			1	5	1				7
1978			2	3	2			1	8
1979			1	2	1	1			5
1980				2	1				3
1981				1	1				2
1982				1	1	1			3
1983				1					1
1984			1	3					4
1985					1				1
1986				3	2				5
1987			1	1	5				7
1988				3	2			1	6
Total ERW	2	11	23	64	67	3		2	172

TABLE 4

CAUSE OF FAILURES OF ERW SEAMS
HAZARDOUS LIQUID PIPELINES
(where metallurgical report is available)

1977 - 1988

Cause of Failures	Service Failure	Hydrotest Failure
Fatigue Crack Initiating from Misalignment	4	
Lack of Fusion (O.D.)	6	24
Lack of Fusion (I.D.)		8
Hook Crack (I.D.)	4	
Selective Corrosion	6	
Hard Spot Microcracks	2	
Corrosion Fatigue (L.O.F.)	3	
Fatique at Lamination in ERW Seam	1	
TOTAL	26	32

TABLE 5

ERW FAILURE DISTRIBUTION BY MANUFACTURERS
HAZARDOUS LIQUID PIPELINES
1977* - 1988

Manufacturer	Service Failures		Hydrotest Failures
National Tube (U.S. Steel)	2		
Youngstown	3		15
Jones & Laughlin	4		10
Kaiser	1		
Republic	2		5
Lone Star			5
Bethlehem	1		
Subtotal	13		35
TOTAL		48	

*Manufacturer not identified on form prior to 1977; manufacturer not identified on all incident report forms from 1977 to present time.

NOTE: There is no data to determine the total mileage of pipe made by each manufacturer so it is not possible to compare the failure rate of different manufacturers.

TABLE 6

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
NATURAL GAS PIPELINE CO. OF AMERICA	1030	1957	615	4-70	1957	YOUNGSTOWN SHEET & TUBE	20	0.250	X52	
MFG. LIGHT & HEAT	1034 1170	1958 1968	805	11-70	1958	YOUNGSTOWN SHEET & TUBE	20	0.250	X52	
WASHINGTON NATURAL GAS CO.	1519	1970	625	12-70	1970	CAL METAL	16	0.312	X52	1 MONTH AFTER INSTALLATION
COMMONWEALTH NATURAL GAS CO.	665	1958	575	12-70	1958	BETHLEHEM	12	0.250	X42	
ARKLA GAS CO.			300	1-71	<1940		12	0.250	B	
N. CAROLINA NATURAL GAS CO.	960	1959	500	4-71	1959		3	0.156	B	
MICH. WISC. PIPELINE CO.	1175	1960	825	4-71	1960	A. O. SMITH	24	0.312	X52	
NORTHERN GAS CO.	625	1970	432	4-71	1951	KAISER	6	0.250		
MICH. WISC. PIPELINE CO.	1063 1297	1956 1968	625	6-71	1956	YOUNGSTOWN SHEET AND TUBE	22	0.281	X52	
TENNESSEE GAS PIPELINE CO.		1960	935	7-71	1960	LONE STAR SHEET & TUBE	10	0.250	X46	
NORTHERN GAS CO.	625	1970	430	9-71	1951	KAISER	6	0.250		
NORTHERN INDIANA PSC	1200	1964	350	11-71	1964		10	0.250	X42	
EL PASO NATURAL GAS CO.			550	11-71	1954	KAISER	10	0.250	X42	
PENNZOIL PIPELINE CO.			474	1-72	1943	YOUNGSTOWN SHEET & TUBE	18	0.250	B	
NATURAL GAS PIPELINE CO. OF AMERICA	800	1957	750	4-72	1957	A. O. SMITH	26	0.250	X52	SEVERE SELECTIVE SEAM CORROSION
MICH. WISC. PIPELINE CO.	898 1127	1949 1969	605	6-72	1949	A. O. SMITH	22	0.250	X52	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
MICH. WISC. PIPELINE CO.	1145	1965	640	6-72	1965	A. O. SMITH	30	0.289	X60	
PIONEER NATURAL GAS CO.			395	9-72		YOUNGSTOWN SHEET & TUBE	16	0.250	B	
SOUTHERN NATURAL GAS CO.	620	1949	469	10-72	1941	REPUBLIC	12	0.250	B	
EL PASO NATURAL GAS CO.	1200	1956	1130	11-72	1949	REPUBLIC	6	0.250	B	
NATURAL GAS PIPELINE CO. OF AMERICA	1200	1972	500	1-73	1972	STUPP CORP.	10	0.188	X42	
LOUISIANA-NEVADA TRANSIT CO.			370	3-73	1940	REPUBLIC	8	0.203	B	
TRANSWESTERN PIPELINE CO.	1110	1960	805	3-73	1960	YOUNGSTOWN SHEET & TUBE	20	0.281	X52	
ALGONQUIN GAS TRANSMISSION CO.	781	1953	500	4-73	1952	ACERO DEL PACIFICO (CHILE)	8	0.250	X30 A	
ALGONQUIN GAS TRANSMISSION CO.	781	1953	500	5-73	1952	ACERO DEL PACIFICO (CHILE)	8	0.250	X30 A	
ALGONQUIN GAS TRANSMISSION CO.	804	1953	488	5-73	1952	ACERO DEL PACIFICO (CHILE)	6	0.250	X30 A	
ALGONQUIN GAS TRANSMISSION CO.	804	1953	485	6-73	1953	ACERO DEL PACIFICO (CHILE)	8	0.250	X30 A	
MICH. WISC. PIPELINE CO.	1085	1959	425	7-73	1959	A. O. SMITH	24	0.281	X52	
COLUMBIA GAS TRANSMISSION CO.	1026 1170	1959 1968	837	8-73	1959	YOUNGSTOWN SHEET & TUBE	20	0.250	X52	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
ALGONQUIN GAS TRANSMISSION CO.	804 1124	1953 1973	500	8-73	1953	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
ALGONQUIN GAS TRANSMISSION CO.	804 1163	1953 1973	450	8-73	1953	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
NORTHERN UTILITIES INC.			700	1-74	1947		6	0.188		
ALGONQUIN GAS TRANSMISSION CO.	780	1953	500	3-74	1952	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
SUGAR BOWL GAS TRANSMISSION CO.			700	3-74	1957		12	0.350	B	
SOUTHERN UNION GAS CO.			497	3-74	1948	A. O. SMITH	12	0.250		SELECTIVE SEAM CORROSION
SOUTHERN NATURAL GAS CO.	640	1948	490	7-74	1940	REPUBLIC	12	0.250	B	
PANHANDLE EASTERN PIPELINE CO.	780	1954	610	7-74	1931	NATIONAL TUBE (U.S. STEEL)	22	0.312	B	
NORTHERN NATURAL GAS CO.	880	1963	400	8-74	1931	YOUNGSTOWN SHEET & TUBE	26	0.312	B	
NORTHERN NATURAL GAS CO.	850	1963	495	8-74	1931	YOUNGSTOWN SHEET & TUBE	26	0.312	B	
NATURAL GAS PIPELINE CO. OF AMERICA	800 858	1949 1973	600	9-74	1947	A. O. SMITH	26	0.250	X	
ALGONQUIN GAS TRANSMISSION CO.	805 1266	1953 1974	625	9-74	1953	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
MICH. WISC. PIPELINE CO.	944 1275	1956 1970	745	11-74	1956	YOUNGSTOWN SHEET & TUBE	22	0.281	X52	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
MICH. WISC. PIPELINE CO.	1041	1949	908	1-75	1949	REPUBLIC	24	0.312	X52	
COLUMBIA GAS TRANSMISSION CO.	1200	1969	790	2-75	1947		20	0.312	X42	
ARKLA GAS CO.	950	1949	660	4-76	1949	YOUNGSTOWN SHEET & TUBE	20	0.250	X46	
NORTHERN GAS CO.	625	1970	365	5-76		KAISER	6	0.250		
CITIZENS' GAS & COKE UTILITY	1200	1966	800	5-76	1966		10	0.250	B	
NORTHERN GAS CO.	831	1963	280	8-76	1931	YOUNGSTOWN SHEET & TUBE	26	0.312		
TEXAS GAS TRANSMISSION CO.			1050	10-76	1944	YOUNGSTOWN SHEET & TUBE	16	0.312	B	
NATURAL GAS PIPELINE CO. OF AMERICA	710 920	1941 1975	630	5-77	1941	A. O. SMITH	26	0.250	X52	
NATURAL GAS PIPELINE CO. OF AMERICA	959	1973	550	5-77	1946	A. O. SMITH	26	0.250	X52	
EXXON GAS SYSTEM INC.	1430	1957	690	5-77	1957	LONE STAR SHEET & TUBE	12	0.250	X46	
NATURAL GAS PIPELINE CO. OF AMERICA	712 940	1941 1973	690	5-77	1941	A. O. SMITH	26	0.250	X52	
COLUMBIA GAS TRANSMISSION CO.	1132	1960	285	9-77	1960	REPUBLIC	10	0.250	X42	
CONSOLIDATED GAS SUPPLY	510 1035	1951 1951	903	10-77	1950	YOUNGSTOWN SHEET & TUBE	20	0.312	X46	
EL PASO NATURAL GAS CO.	1330	1970	750	4-78		YOUNGSTOWN SHEET & TUBE	12	0.250	B	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	PIPE DATA WALL	PIPE DATA GRADE	CAUSE OF FAILURE
NATURAL GAS PIPELINE CO. OF AMERICA	916	1975	620	6-78	1947	A. O. SMITH	26	0.250	X52	
NATURAL GAS PIPELINE CO. OF AMERICA	930	1973	600	6-78		A. O. SMITH	26	0.250	X52	
NATURAL GAS PIPELINE CO. OF AMERICA	930	1973	600	6-78		A. O. SMITH	26	0.250	X52	
MICH. WISC. PIPELINE CO.	1214	1959	860	6-78	1959	A. O. SMITH	24	0.312	X52	
TEXAS GAS TRANSMISSION CO.	868	1965	365	8-78	1940	YOUNGSTOWN SHEET & TUBE	18	0.250	B	
MICH. WISC. PIPELINE CO.	1365 1831	1958 1978	735	10-78	1958	REPUBLIC	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1365 1844	1958 1978	635	11-78	1958	REPUBLIC	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1365 1844	1958 1978	635	11-78	1958	REPUBLIC	12	0.250	X46	
SAN DIEGO GAS & ELECTRIC CO.	1548	1974	553	12-78	1974	NATIONAL TUBE (U.S. STEEL)	16	0.250	X52	
ALGONQUIN GAS TRANSMISSION CO.	781	1953	453	2-79	1952	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
ALGONQUIN GAS TRANSMISSION CO.	781	1953	450	2-79	1952	ACERO DEL PACIFICO (CHILE)	8	0.250 A	X30	
NORTHERN NATURAL GAS CO.	645	1956	400	4-79	1931	REPUBLIC	14	0.250	(25 KSI)	
MICH. WISC. PIPELINE CO.	1365 1804	1958 1971	600	5-79		REPUBLIC	12	0.250	X46	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	PIPE DATA WALL	PIPE DATA GRADE	CAUSE OF FAILURE
NATURAL GAS PIPELINE CO. OF AMERICA	1459	1965	712	8-79	1965	YOUNGSTOWN STEEL & TUBE	20	0.235	X60	
COLORADO INTERSTATE GAS CO.	955 870	1950 1978	800	8-79	1950	YOUNGSTOWN STEEL & TUBE	20	0.281	X46	
EASTERN OHIO GAS CO.			288	10-79	1943		20	0.312	B	
EASTERN OHIO GAS CO.			280	10-79	1942		18	0.375	B	
EL PASO NATURAL GAS CO.			500	10-79	1949	A. O. SMITH	16	0.250	X52	
MICH. WISC. PIPELINE CO.	1631	1965	745	9-80	1965	STUPP CO.	12	0.250	X42	
PANHANDLE EASTERN PIPELINE CO.	900	1955	739	10-80	1940	A. O. SMITH	24	0.281 (48 XSI)		
TENNESSEE GAS PIPELINE CO.	1010 1113	1950 1973	612	3-81	1950	A. O. SMITH	24	0.281	X52	
EL PASO NATURAL GAS CO.	715	1963	645	6-81			10	0.188	X42	
MICH. WISC. PIPELINE CO.	1631	1965	700	10-81	1965	STUPP CO.	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1631	1965	700	10-81	1965	STUPP CO.	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1631	1965	700	10-81	1965	STUPP CO.	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1631	1981	700	11-81	1965	STUPP CO.	12	0.250	X46	
MICH. WISC. PIPELINE CO.	1631	1965	700	10-81	1965	STUPP CO.	12	0.250	X46	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
MOUNTAIN FUEL SUPPLY CO.	900	1975	520	6-82		NATIONAL TUBE (U.S. STEEL)	3	0.188	B	
MICH. WISC. PIPELINE CO.	1039 1361	1949 1979	800	6-82	1949	A. O. SMITH	24	0.312	X52	
CONSOLIDATED GAS SUPPLY CO.			745	6-82	1950	YOUNGSTOWN STEEL & TUBE	18	0.312	X42	
MICH. WISC. PIPELINE CO.	944 1252	1956 1981	740	8-82	1956	A. O. SMITH	30	0.344	X52	
NATURAL GAS PIPELINE CO. OF AMERICA	970	1941 1975	526	10-82	1941	A. O. SMITH	26	0.250	X52	
CONSOLIDATED GAS SUPPLY CO.	1120	1966	814	2-83	1951	YOUNGSTOWN SHEET & TUBE	18	0.344	X46	
NATURAL GAS PIPELINE CO. OF AMERICA	1002	1975	600	5-83	1941	A. O. SMITH	26	0.250	X52	
TEXAS UTILITIES FUEL CO.	950	1962	580	7-83	1962	LONE STAR SHEET & TUBE	16	0.250	X42	
TEXAS UTILITIES FUEL CO.	1250	1979	625	8-83			12	0.250	X42	
LONE STAR GAS CO.	700	1953	855	12-83	1953		12	0.250	B	
UNITED GAS PIPELINE CO.	426 508	1947 1961	520	2-84	1947		6	0.188	(24 KSI)	
ARKLA	1035	1977	680	9-84	1949	YOUNGSTOWN SHEET & TUBE	20	0.188	X46	
VALERO TRANSMISSION CO.			310	2-85	1932	REPUBLIC	6	0.188	B	
EL PASO NATURAL GAS			1210	12-85	1956	ACME NEWPORT	6	0.188	B	

TABLE 6 (continued)

SUMMARY OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES (cont.)
1970 - 1988

OPERATOR	HYDROSTATIC PRESSURE	TESTS DATE(S)	FAILURE PRESSURE	FAILURE DATE	INST.	MANUFACTURER	PIPE DATA DIA	WALL	GRADE	CAUSE OF FAILURE
WESTAR	1449	1970	960	10-86	1970	NATIONAL TUBE (U.S. STEEL)	12	0.250	X46	
EL PASO NATURAL GAS			1210	1-86	1956	ACME NEWPORT	6	0.88	(35 KSI)	
ARKLA	1100	1977	750	2-86	1950	YOUNGSTOWN SHEET & TUBE	20	0.250	X46	
NORTHERN NATURAL GAS CO.			760	4-86	1951	A. O. SMITH	26	0.281	B	SEAM 75'
CONSOLIDATED GAS TRANS. CORP.	1449	1970	950	10-86	1954		10	0.344	B	SEAM SPLIT
HOUSTON PIPELINE	1502	1975	640	10-86	1976	AMERICAN	12	0.250	B	SEAM SPLIT 40'
NATURAL GAS PIPELINE CO.	948	1951		10-86	1951	A. O. SMITH	30	0.344	B	SEAM L.O.F.
UNITED GAS PIPELINE CO.		1952	834	11-86	1952	A. O. SMITH	30	0.375	B	SEAM SPLIT 36' 10"

TABLE 7

ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES
CONSTRUCTION DECADE DISTRIBUTION
1970 - 1986

Event Year	1930s	1940s	1950s	1960s	1970s	1980s	Unk.	Totals
	CONSTRUCTION DECADE							
1970			3		1			4
1971	1		5	3				9
1972		4	1	1			1	7
1973		1	8	1	1			11
1974	3	4	4					11
1975		2						2
1976	1	2		1			1	5
1977		3	2	1				6
1978		2	4		1		3	10
1979	1	3	1	1			1	7
1980		1		1				2
1981			1	5			1	7
1982		2	2				1	5
1983		1	2	1			1	5
1984		2						2
1985	1		1					2
1986			6		2			8
Total ERW	7	27	40	15	5		9	103

TABLE 8

ERW FAILURE DISTRIBUTION BY MANUFACTURER*
NATURAL GAS TRANSMISSION PIPELINES
1970 - 1988

Manufacturer	Service Failures
National Tube	4
Youngstown Sheet & Tube	19
Kaiser	2
Republic	12
Lonestar	3
Bethlehem	1
A. O. Smith	21
Cal Metal	1
Stupp	5
Acero del Pacifico	10
ACME Newport	2
TOTAL	80

*Where the manufacturer was identified on the incident report form.

NOTE: There is no data to determine the total mileage of pipe made by each manufacturer so it is not possible to compare the failure rate of different manufacturers.

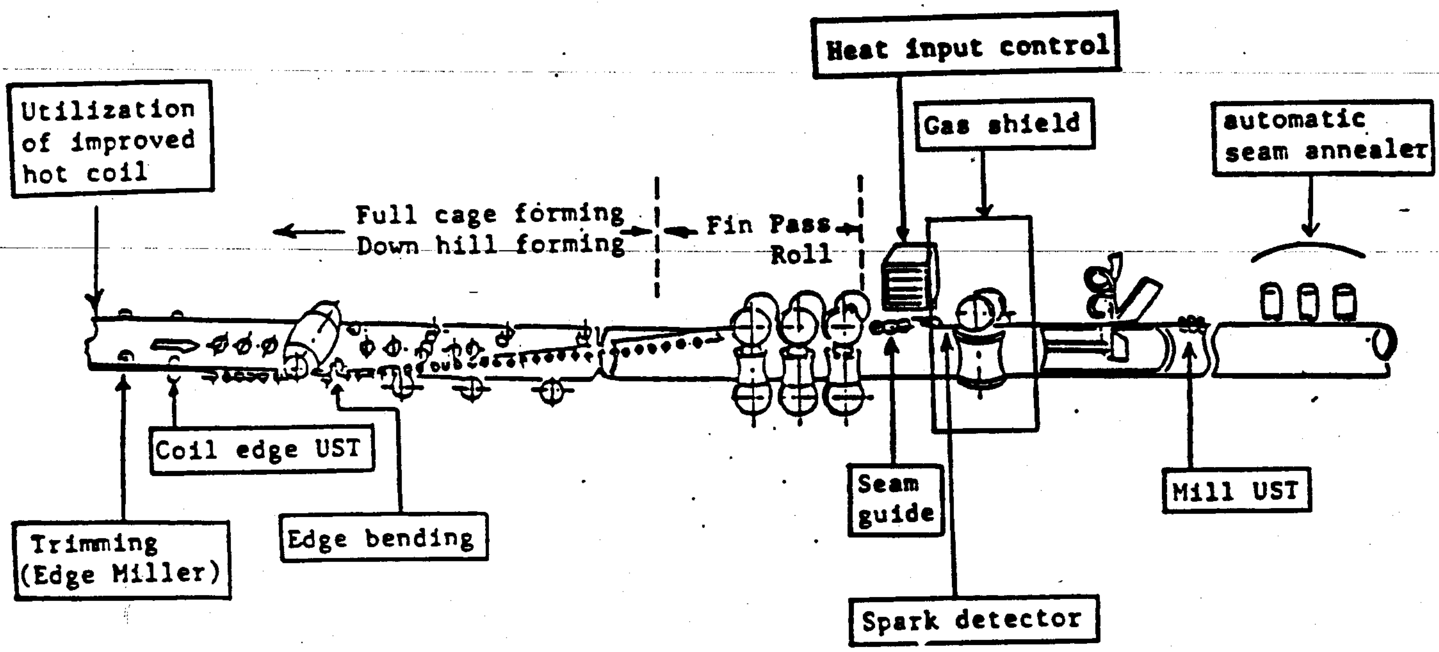


Figure 1 Schematic Representation of the Electric Resistence Welding (ERW) Process

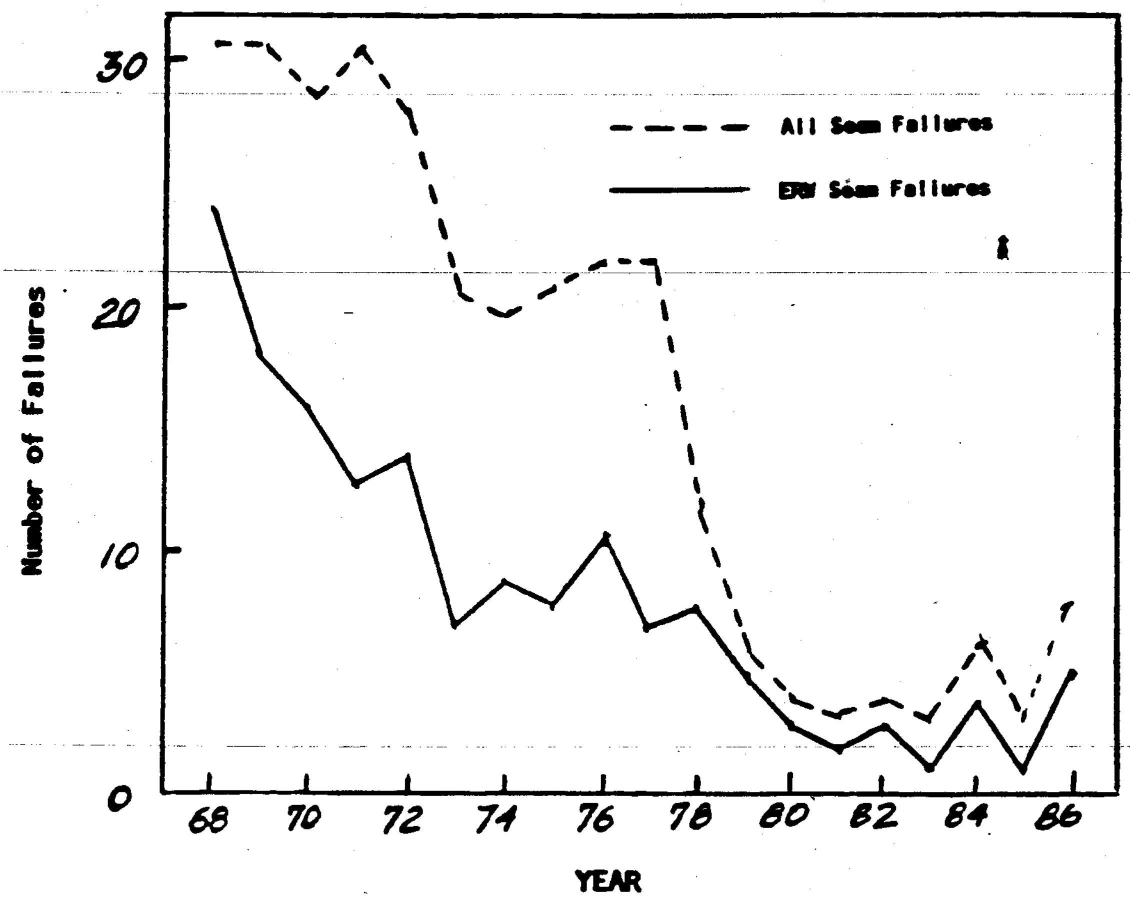


Figure 2 Graph of Hazardous Liquid Pipeline Seam Failures (1968 - 1986)

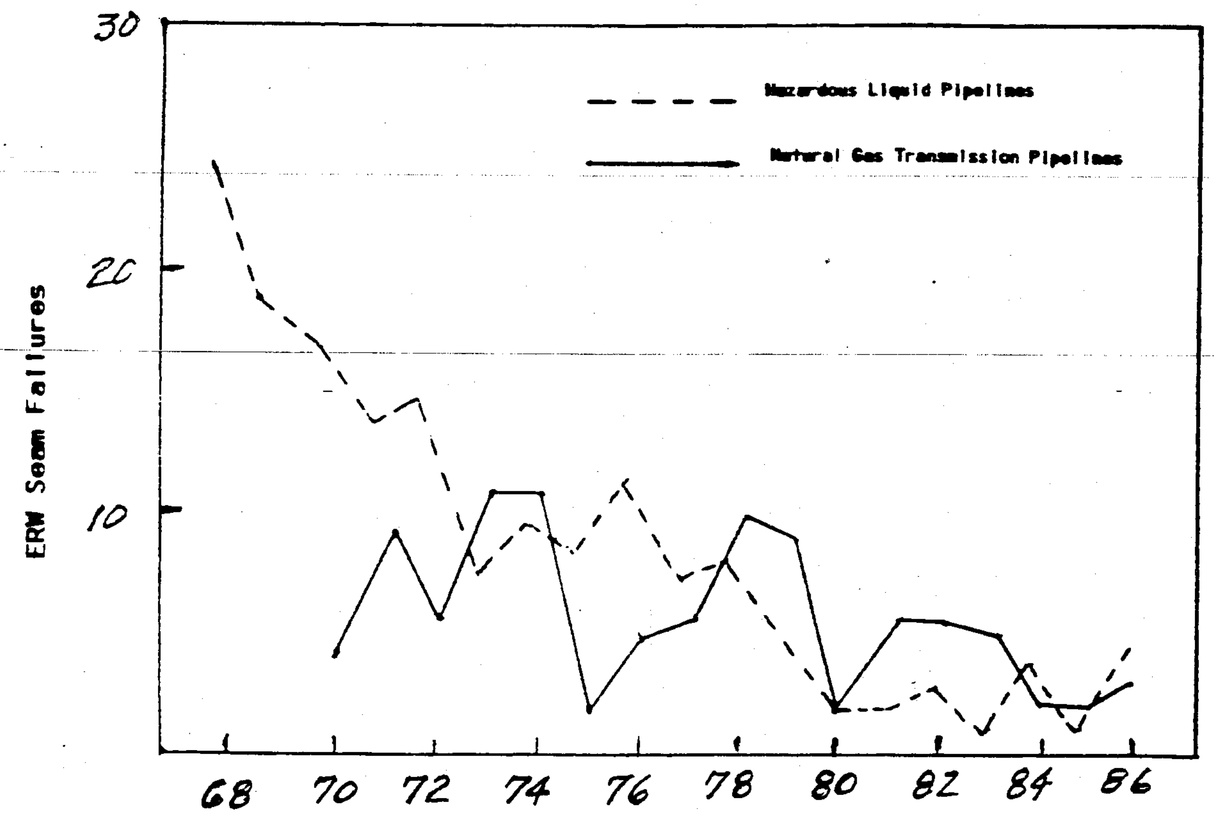


Figure 3 Graph of ERW Seam Failures (1968-1986) Hazardous Liquid and Gas Transmission Pipelines

APPENDIX A

TYPICAL EXAMPLES OF METALLURGICAL EXAMINATIONS OF ERW PIPELINE FAILURES

1. Metallurgical Examinations of Hazardous Liquid Pipeline Failures

The following are typical examples of metallurgical examinations of failures in the ERW seam of hazardous liquid pipelines:

1.1 Colonial Pipeline Company

In May 1979, 3 years after a Colonial products pipeline, 32-inch diameter x 0.281-inch wall thickness (w.t.) API 5LX-52, was installed, a rupture occurred in the ERW seam. Metallurgical analysis of the fractured seam revealed that the cause of the failure was a fatigue crack which had grown to critical size due to both pre-installation rail transport loading conditions and cyclic pressure fluctuations in service following installation. The fatigue crack initiated from an internal misalignment (illustrated in Appendix C, Figure 4).

1.2 Exxon Pipeline Company

In May 1979, an 18-inch diameter x 0.281-inch w.t. API 5LX-45 Exxon products pipeline ruptured in an ERW seam. A metallurgical analysis of the fracture confirmed the presence of both external lack of fusion and extensive selective corrosion. These defects were cited as the cause of the failure.

1.3 Minnesota Pipeline Company

In January 1980, a 16-inch diameter x 0.250-inch w.t. API 5LX-52 Minnesota Pipeline Company products pipeline ruptured in an ERW seam. The fracture origin was traced to an inside diameter lack of fusion and an outside diameter hook crack believed to have extended to critical size under corrosion fatigue cycling.

1.4 Lakehead Pipeline Company

In May 1980, a Lakehead Pipeline Company 34-inch diameter x 0.281-inch w.t. API 5LX-52 products pipeline ruptured in an ERW seam under conditions similar to those described in 1.3 above.

1.5 Williams Pipe Line Company

In August and October 1983, ruptures occurred on an 8-5/8 inch diameter x 0.250-inch w.t. API 5LX-42 (No. 2-8-inch line) and on a 12-inch diameter x 0.250-inch w.t. API 5LX-42 products line. Both ruptures occurred in ERW seams, the former due to a hook crack which extended under overpressure conditions, the latter due to a lack of fusion on the outside diameter.

1.6 Southern Pacific Pipeline Company

In March 1984, a 12-inch diameter x 0.250-inch w.t. API 5LX-46 ERW seam welded pipeline ruptured. A failure analysis revealed that selective seam corrosion was the cause of failure.

1.7 Minnesota Pipeline Company

In February 1984, a fatigue crack, which had initiated at an 18-inch long delamination at the edge of an ERW seam weld in a 16-inch diameter x 0.250-inch w.t. API 5LX-52 pipe, propagated through the pipe wall and caused the seam to rupture.

1.8 Williams Pipe Line Company

In November 1984, the Williams Pipe Line No. 2-8-inch line ruptured at an ERW seam. A failure analysis revealed that the cause of the failure was a lack of fusion on the O.D. of an 8-inch diameter x 0.250-inch w.t. API 5LX-42 pipeline.

1.9 Williams Pipe Line Company

In May 1986, the Williams Pipe Line Company No. 2-8-inch line ruptured at an ERW seam. A study of the failure revealed a lack of fusion on the O.D. of an 8-inch diameter x 0.250-inch w.t. API 5LX-42 pipeline.

1.10 Williams Pipe Line Company

On July 8, 1986, the Williams Pipe Line Company No. 2-8-inch pipeline ruptured along an ERW seam. An extensive failure analysis revealed that selective corrosion due to inadequate cathodic protection caused the rupture in the 8-inch diameter x 0.250-inch w.t. API 5LX-42 pipeline.

1.11 San Diego Pipeline Company

In November 1986, a rupture occurred in an ERW seam of a 10-inch diameter x 0.219-inch w.t. API 5LX-52 products pipeline owned by the San Diego Pipeline Company. An extensive failure investigation revealed that corrosion fatigue initiating at an internal lack of fusion was the probable cause of the rupture.

1.12 Lakehead Pipeline Company

In October 1986, a 34-inch diameter x 0.281-inch w.t. API 5LX-52 ERW seam rupture occurred in a Lakehead Pipeline Company line. The cause of failure was determined to be a one-half-inch long lack of fusion defect that extended entirely through the wall thickness of the pipe.

1.13 Williams Pipe Line Company

During a hydrostatic testing program initiated in September 1986 as a result of the incident described in section 1.10, the Williams Pipe Line Company's No. 2-8-inch line suffered seven splits in the ERW seams due to lack of fusion defects.

During the same hydrostatic testing program, the No. 1-8-inch line was subjected to similar tests with the result that three ERW seam split were found to have initiated from outside lack of fusion defects.

1.14 Continental Pipeline Company

In March 1987, Continental Oil Company experienced a rupture on its 8-inch diameter x 0.250-inch w.t. API 5LX-52 Seminole pipeline. A metallurgical analysis revealed severe selective seam corrosion which nearly penetrated the wall at the fracture origin. It was confirmed that low cathodic protection potentials were measured near the fracture origin.

1.15 Williams Pipe Line Company

During the first and second quarter of 1987, Williams Pipe Line Company continued the hydrostatic test program initiated in 1986. Six failures resulted - one from a fatigue crack initiating at an internal mismatch on the seam and five due to lack of fusion. These failures occurred on the Williams Pipe Line No. 1-6 pipeline from Alexandria to Grand Forks.

1.16 Mid America Pipeline Company

In April 1987, Mid America Pipeline Company (MAPCO) experienced a rupture in an 8-inch diameter x 0.219-inch w.t. API 5LX-52 products pipeline. A failure analysis revealed the cause of the failure to be hydrogen stress cracking of an embrittled zone in the ERW seam. Such a defect is virtually impossible to detect by any known method.

Pursuant to the aforementioned incident, MAPCO conducted a comprehensive hydrostatic test program designed to eliminate defects that might grow under environmental conditions to a critical size. During the test, 20 failures occurred in ERW seams. In all but one case, the fracture origin was traced to a lack of fusion defect on the inside, mid wall, or outside diameter. One failure was attributed to a hard spot in the seam.

1.17 Mid America Pipeline Company

On July 22, 1988, MAPCO experienced a rupture in an 8-inch diameter x 0.219-inch w.t. API 5LX-52 natural gas liquids pipeline at a cased highway crossing. A metallurgical examination revealed the cause of the failure to be selective corrosion of the ERW seam. The penetration at the ERW bond line extended about 72 percent of the way through the pipe wall, initiating the rupture.

1.18 Minnesota Pipeline Company

On December 1, 1988, Minnesota Pipeline Company's 16-inch diameter x 0.250-inch w.t. API 5LX-52 pipe failed at a lamination that had opened during the ERW welding process. Subsequent analysis revealed the cause of failure to be a fatigue crack which had penetrated the outer ligament of severe lamination at the ERW seam.

1.19 Shell Pipeline Company

On December 24, 1988, Shell Pipeline Company's 22-inch diameter x 0.344-inch w.t. API 5LX-46 pipe failed due to a hook crack at the ERW seam. The failure resulted in the total fracture of the ERW seam in one 48.8-foot long pipe length. The failure resulted in a crude oil spill of approximately 20,500 barrels which flowed down the tributary of the Gasconade River and continued downstream into the Missouri and Mississippi Rivers.

2. Metallurgical Examinations of Gas Transmission Pipeline Failures

The following are typical examples of metallurgical examinations of failures in the ERW seam of gas transmission pipelines, for which a detailed report was available:

2.1 Natural Gas Pipeline Company of America

In April 1972, an ERW seam split occurred on a 26-inch diameter x 0.250-inch w.t. API 5LX-52 natural gas transmission pipeline. An examination of the failure analysis report of this incident revealed:

(1) "The failure originated in the longitudinal flash weld (one type of ERW weld) and was caused by localized external corrosion concentrated along the weld line."

(2) "The localized external corrosion was most severe along the weld line because of galvanic effects related to entrapped oxides and differences in microstructure of the weld. The net result was crevice (selective) corrosion, which developed an external deep narrow crack-like groove that extended across the wall of the pipe and was the origin of the failure."

It was found that selective corrosion had reduced the wall thickness from 0.257 inches to 0.170 inches along the edge of the weld near the origin of the failure. The susceptibility of the weld line to localized corrosion was evidenced by loss of metal along the bond line, in some sections to more than 90 percent of the wall thickness.

Figures B-1, B-2, B-3, and B-4 (Appendix B) illustrate the highly confined and directional nature of the selective corrosion. The schematic reconstruction of Figure B-4 is based on evidence obtained from the preceding figures and illustrates a nearly complete penetration of the pipe wall.

2.2 Southern Union Gas Company

In March 1974, a 12-inch diameter x 0.250 w.t. (grade unknown) ERW seam split occurred in a natural gas transmission pipeline. A review of the metallurgical analysis of the Southern Union Gas Company's failed pipeline resulted in the following conclusions:

(1) "The failure was a brittle fracture that initiated in a crack in the longitudinal flash weld (one type of ERW weld) of the A. O. Smith pipe. The crack was caused by crevice corrosion in the longitudinal flash weld that was located at the bottom of the pipeline ditch."

(2) "The localized crevice corrosion was due to the galvanic behavior of the entrapped oxides and the microstructure in the fusion line and heat affected zone of the flash weld, combined with the anodic characteristics of the crack tip associated with this type of corrosion. The net result was a narrow crack-like groove which extended though nearly the entire wall thickness of the pipe. This groove grew through continued corrosion to the critical crack size required to initiate the brittle fracture."

Figures B-5, B-6, B-7, and B-8 illustrate the features of the crevice (selective) corrosion which bear a striking resemblance to that of the incident discussed in section 2.1. This particular pipeline was not coated, but was under "hot spot" cathodic protection using anodes at regions of historically severe metal loss.

Figure B-7 clearly illustrates the severity of selective corrosion attack on the bond line. The dark line is the result of a hydrochloric acid etch that has selectively attacked the weld bond line. The accelerated selective attack is representative of the slower selective corrosion attack under field service conditions where cathodic protection is inadequate.

2.3 Arkansas Louisiana Gas Company

In September 1984, the Arkansas Louisiana Gas Company Line S, a 20-inch diameter x 0.250-inch w.t. API 5LX-46 line pipe, ruptured in the ERW seam. Metallurgical studies were conducted on the failed pipe and the conclusions suggested that the failure was caused by hydrogen stress cracking in a hard spot in the ERW seam. Portions of the seam were found to have high hardness levels (Rockwell C43) consistent with susceptible martensitic grain structures. The cathodic protection system was suspected to have been charging the line to minus 1.2 volts which, in the presence of a coating defect, could have resulted in hydrogen charging which results in stress cracking. Such a high level of charging has also been linked to coating disbondment.

APPENDIX B

PHOTOS OF ERW SEAM FAILURES IN GAS TRANSMISSION PIPELINES

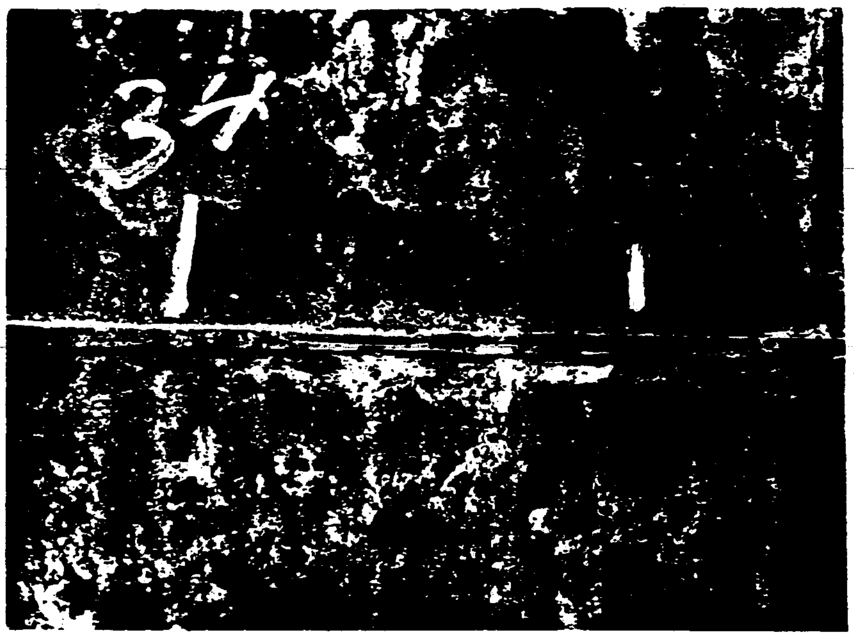


Figure B-1

View of corrosion at flash weld in pipe adjacent to that in which the failure originated. The evidence is that the failure originated at a location where similar corrosion had occurred in the flash weld.

Figure B-2 1 X

Specimens from opposite sides of origin area showing details of corrosion on outside surface at the weld. The specimens are matched together as accurately as possible based on fracture and surface details preparatory to cutting cross sections for metallographic examination.

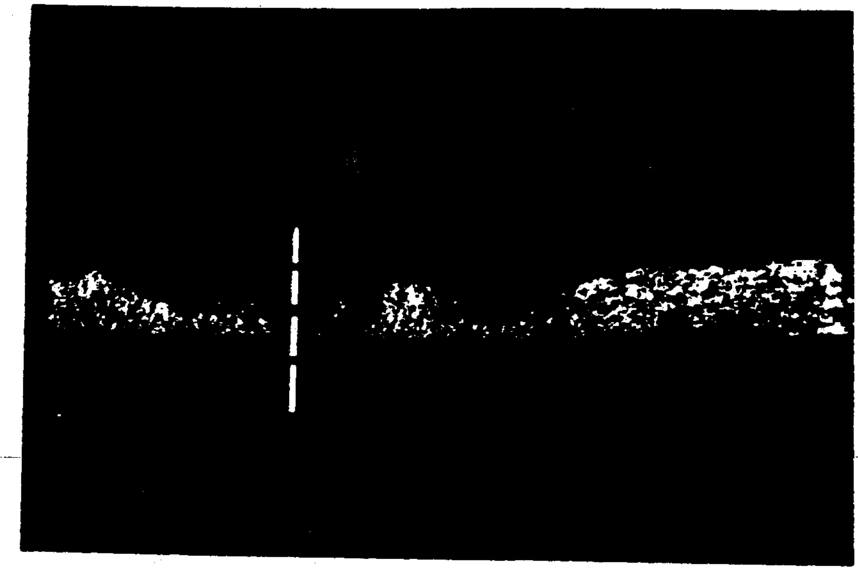


Figure B-3a

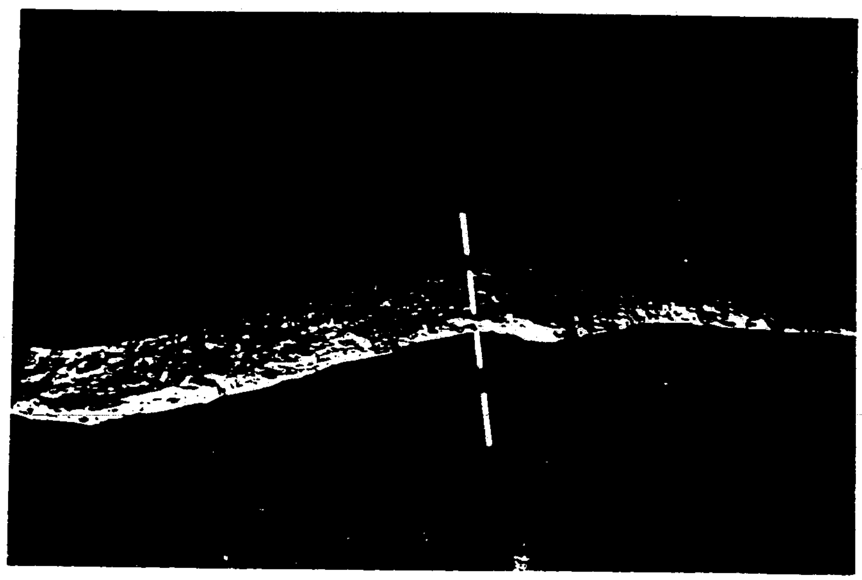


Figure B-3b

Figure B-3

Matching fracture faces of specimens shown in Figure B-2. The black areas on the fracture face from the north side (Figure B-3a) appeared to be corroded crack faces that were present prior to the rupture. The south side of the fracture (Figure B-3b) was black and had a burnished appearance. Indications are that the coating melted and baked onto the surface, obscuring details of the fracture. —— The dashed lines show the location of the cross section shown in Figure B-4.

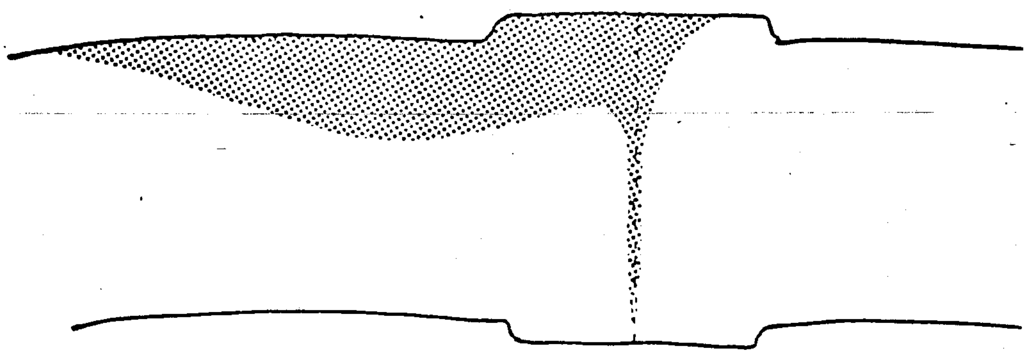


Figure B-4

Sketch based on evidence indicated by Figures B-1, B-2, and B-3 illustrating how localized corrosion (corroded areas shown by dots) along the flash weld extended across the wall and developed a deep narrow groove that had the effect of a crack with sufficient depth and length to initiate the failure.

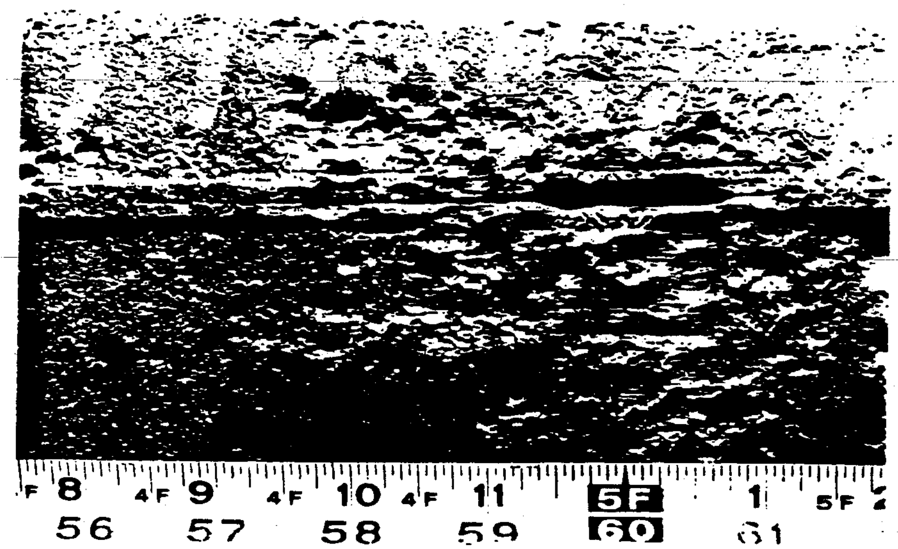


Figure B-5

Close-up views of crevice corrosion in the longitudinal flash weld and localized attack of adjacent base metal.

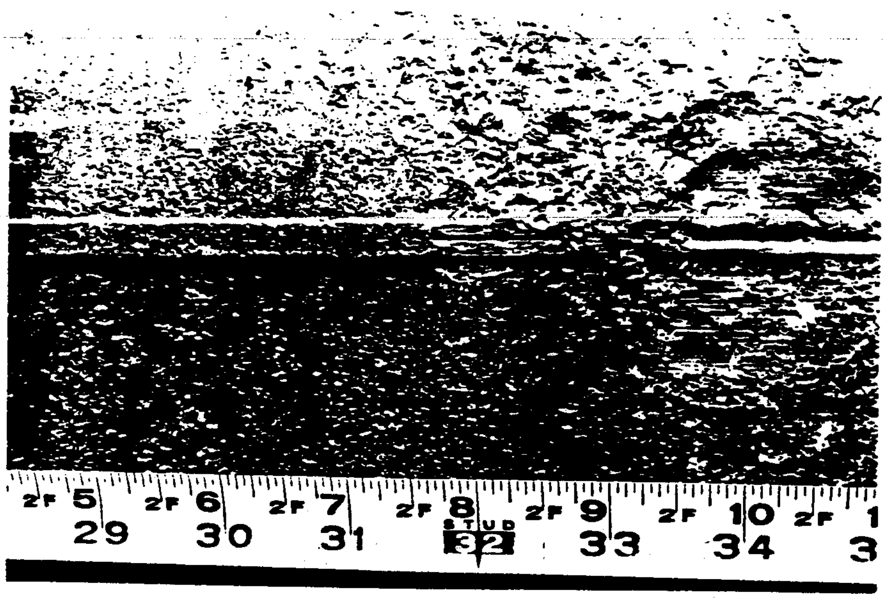


Figure B-6

Flash weld and base material illustrating the location of the deep crevice corrosion in the flash weld. This attack was not uniform over the entire length of pipe, but confined to localized areas.

The first five types of discontinuities are manufacturing quality control related while the other three involve an interaction between manufacturing defects and some form of environmental attack.

The reference numbers appearing in brackets indicate the specific metallurgical failure analysis describing the defect and its relationship to the seam failure in Tables 1 and 6.

1. Lack of Fusion

The most often encountered defect is lack of fusion. Figure C-2 illustrates a typical lack of fusion defect on the outside diameter. Several reasons, such as power surges or interruptions, contact arcing, insufficient upset, trapped oxides on the edge of the skelp, or improper edge trimming, offer a possible explanation for lack of fusion.

2. Hook Cracks

A typical hook crack is illustrated in Figure C-3. This type of cracking occurs during the upset portion of the weld cycle. Such defects typically occur in pipe containing nonmetallic inclusions. In many cases, a hook crack results from the separation of adjacent planes occurring during weld upset due to plane of weakness created by the layer of inclusions between grain boundaries.

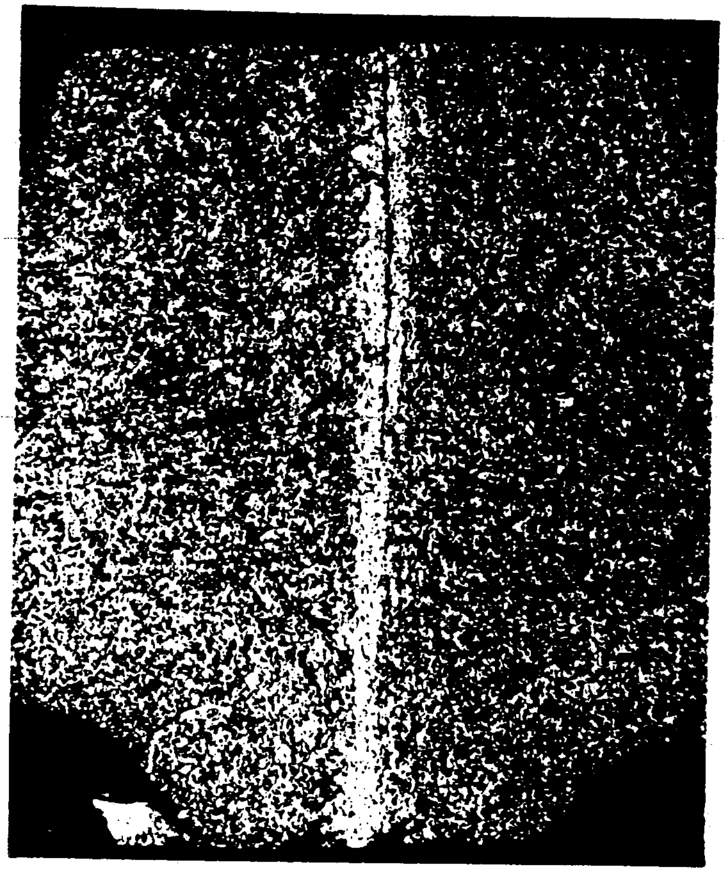


Figure B-7

10 X
HCl Etch

Macro etched sample taken from an uncorroded area of the pipe showing the weld line. The deeply etched dark line in the weld illustrates its susceptibility to accelerated corrosive attack; a result of entrapped oxides and microstructure of the weld line.

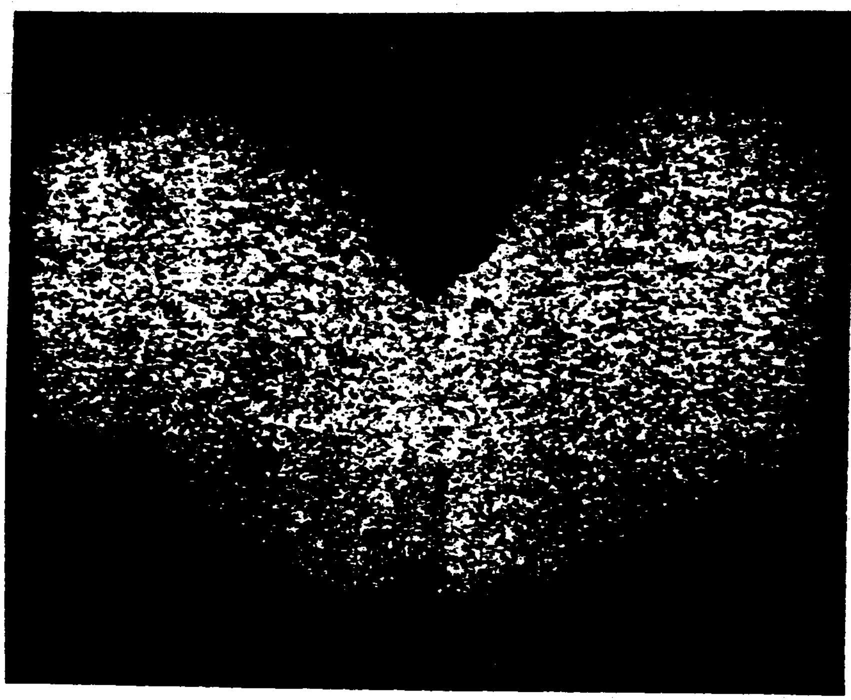


Figure B-8

10 X
HCl Etched

Photomacrograph illustrating the crevice corrosion penetrating partially through the weld.

APPENDIX C

DESCRIPTION OF ERW PIPE FAILURE MECHANISMS

APPENDIX C

DESCRIPTION OF ERW PIPE FAILURE MECHANISMS

The ERW process under normal production conditions produces sound welds, which, in the absence of environmental attack, will have a long life. Figure C-1 illustrates a typical sound ERW weld seam in section. During the welding process, a number of production errors can cause defects in the finished weld. While these production errors are infrequent, they have resulted in failures. Following manufacture, environmental factors, such as corrosion and/or fatigue, can act upon welds whether defect free or not. From Tables 1 and 6 summarizing failures in the seams of ERW pipelines carrying hazardous liquids and natural gas, the available metallurgical reports describing the causes of failure show that most ERW failures are caused by one of the following:

1. Lack of fusion (external, buried, or internal)
2. Hook cracks
3. Nonmetallic inclusions
4. Misalignment (high/low)
5. Excessive trim
6. Fatigue/corrosion fatigue
7. Selective corrosion (crevice corrosion)
8. Hard spots subject to embrittlement and stress cracking
9. Fatigue at lamination/ERW interface

3. Nonmetallic Inclusions

Trapped oxides or particles, such as manganese sulfide, can exist in the steel during the plate fabrication states. Such inclusions generally occur as linear regions following the grain flow during plate rolling operations. During weld upset in the ERW welding process, the grain flow patterns become curved as in Figure C-4.

4. Misalignment

Some failures in the ERW seam have been attributed to the edges of the plate not meeting in precise alignment. The result of such misalignment is shown in Figure C-5. The upper figure shows the typical geometry of misalignment which is eliminated by surface grinding on the O.D. of the pipe, but remains on the I.D. The lower figure shows a magnified view revealing a fatigue crack initiating at the toe of the misalignment.

5. Excessive Trim

Following the welding process, the excess flash is trimmed from both the O.D. and the I.D. If the trimming cutter or wall thickness are not precisely matched, excessive trim can result as shown in Figure C-6. Such a geometry creates severe stress concentrations which can result in crack initiation sites.

6. Fatigue

Fatigue cracking generally occurs in liquid lines if a preexisting initiation site lies in a region of sufficiently high cylic stress. Such initiation sites are shown in Figures C-2 through C-6. Figure C-5 specifically illustrates a fatigue crack which has begun to propagate through the pipe wall. Figure C-9 illustrates a fatigue crack which has propagated through the outer ligament of a lamination at an ERW weld.

7. Selective Corrosion

Selective corrosion can occur along the carbon-depleted ferritic bond line of an ERW weld seam. The actual mechanism is poorly understood but believed to result from slight metallurgical and electrochemical differences in potential, rendering the ERW bond line anodic with respect to the rest of the weld. It appears that the selective attack is promoted along the grain boundaries which curve to the surface as a result of the upsetting step during welding. Each boundary serves as a microcrevice susceptible to corrosion attack. Figure C-7 illustrates two types of selective corrosion involved in pipeline failures. Figures C-7(a) and C-7(b) illustrate the variation in depth between two sections taken approximately 1-inch apart from the Williams pipeline in

Mounds View. Figure C-7(c) illustrates highly selective wedge-like attack along the bond line viewed normal to the fracture plane of the Seminoe Pipeline.

8. Hard Spots

Failures can be caused by hard spots which may result during manufacture from arc strikes, improper current or voltage control, or accidental quenching of the heated microstructure. The embrittlement associated with hard spots arises from the rapid cooling which may produce a martensitic grain structure with high hardness. Microcracks can initiate at hard spots and continue to grow in service due to sulfide stress cracking, hydrogen embrittlement, fatigue, or corrosion. Figure C-8 illustrates a hard spot induced failure which was initiated on the O.D. in the darkly shaded heat affected zone of high hardness.

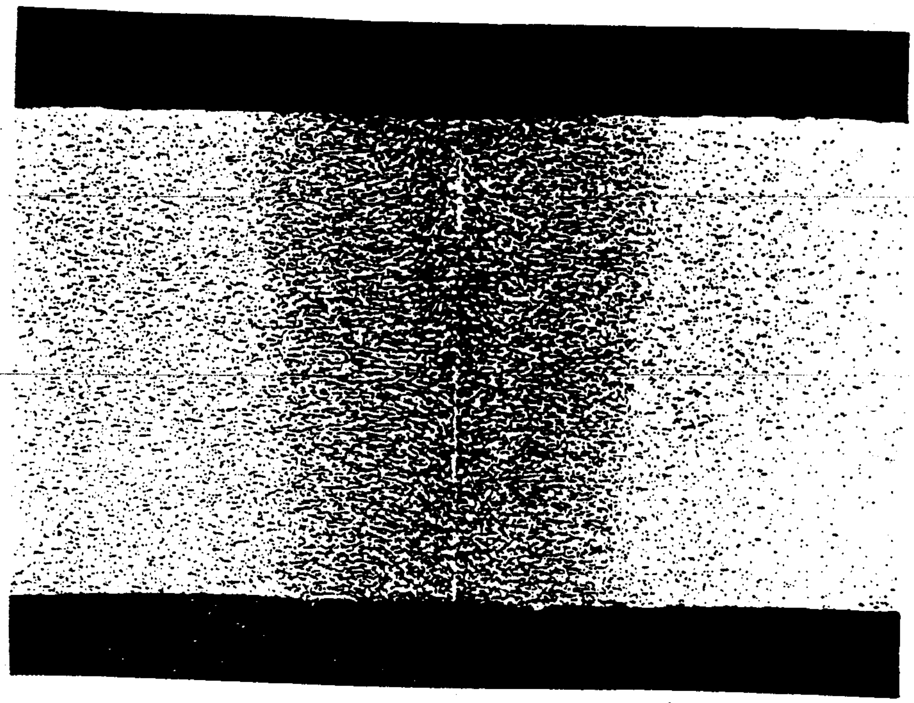


Figure C-1 Cross Section Illustrating a Normal ERW Seam

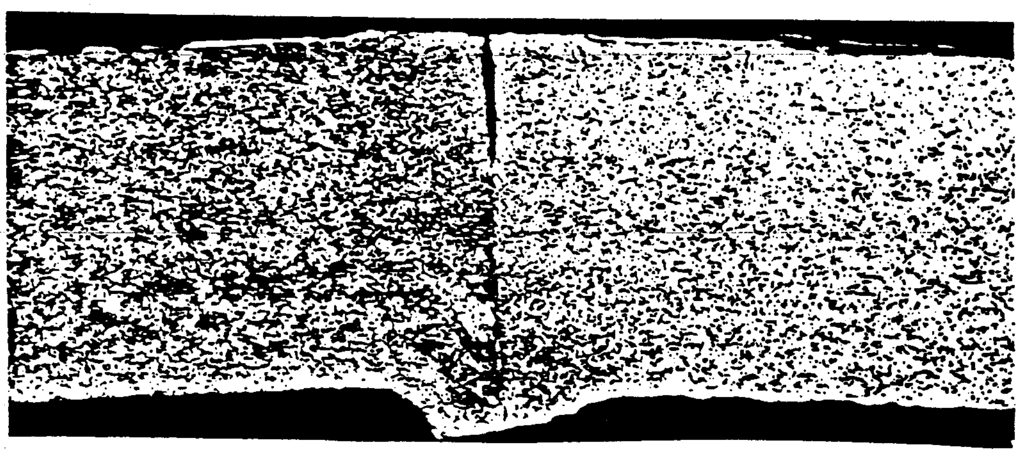


Figure C-2 Lack of Fusion Penetrator From the Outside Diameter

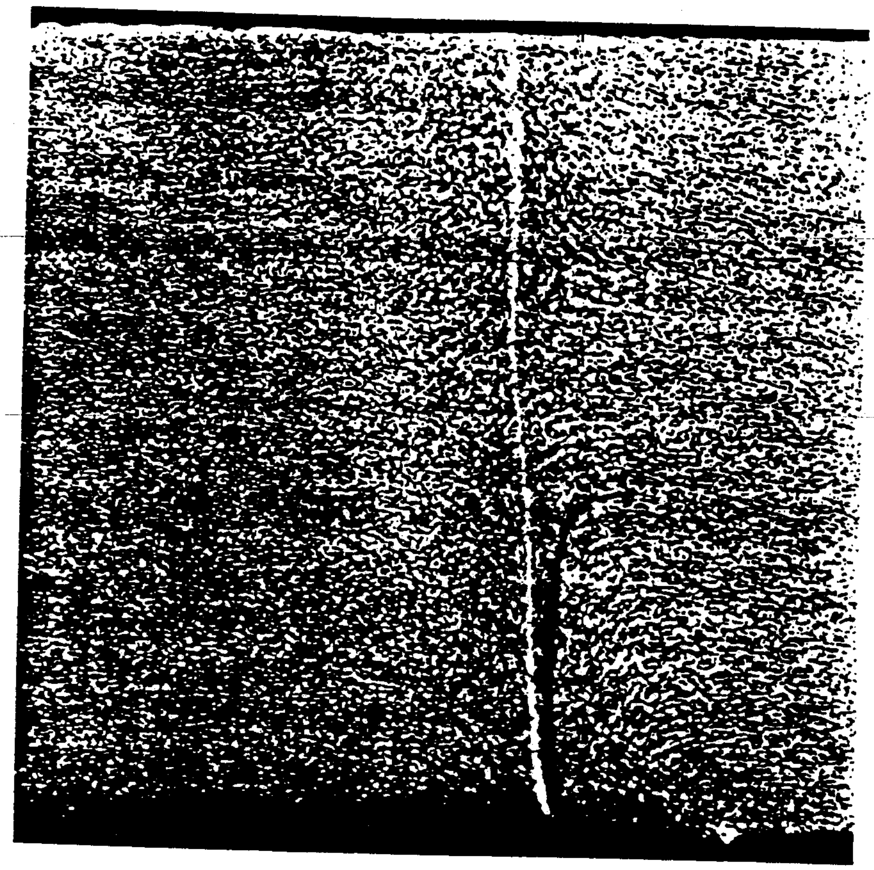


Figure C-3 Hook Crack Initiating From the Inside Diameter

Figure C-4 Nonmetallic Inclusions Aligned With Grain Flow

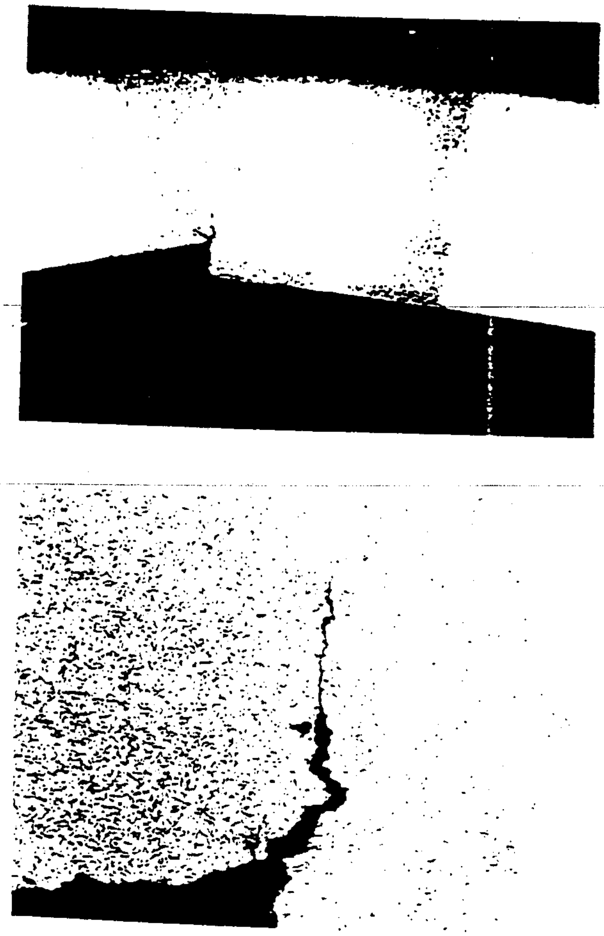


Figure C-5 Misalignment

(a) Misalignment on Inside Diameter (outside ground flush)

(b) Fatigue Crack Initiating From Toe of Misalignment (magnified view of (a))

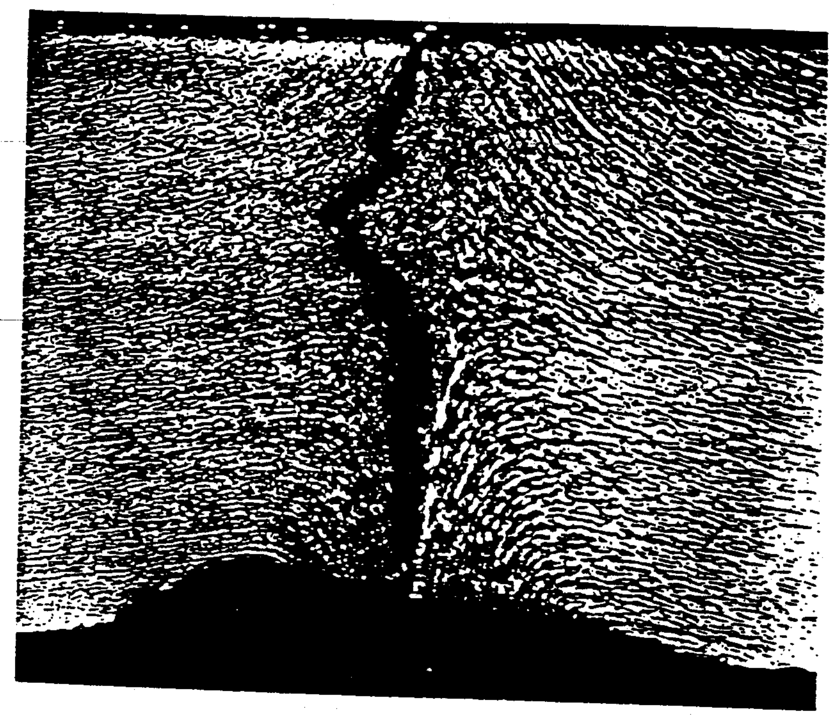
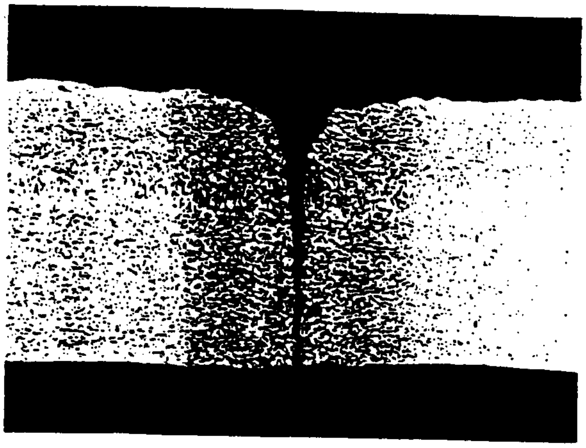
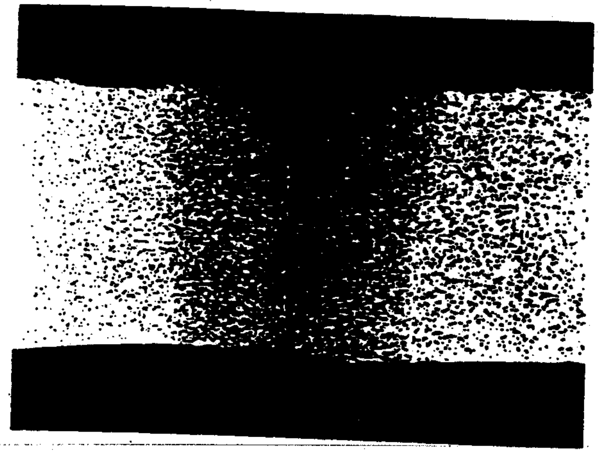


Figure C-6 Excessive Trim on the Inside Diameter



(a) Section From Station 71.5
WPL, Mounds View



(b) Section From Station 71.78
WPL, Mounds View

(c) Fracture Face of Seminoe Pipeline
Showing Selective Corrosion Wedges
Nearly Penetrating Wall Thickness

Figure C-7 Selective Corrosion

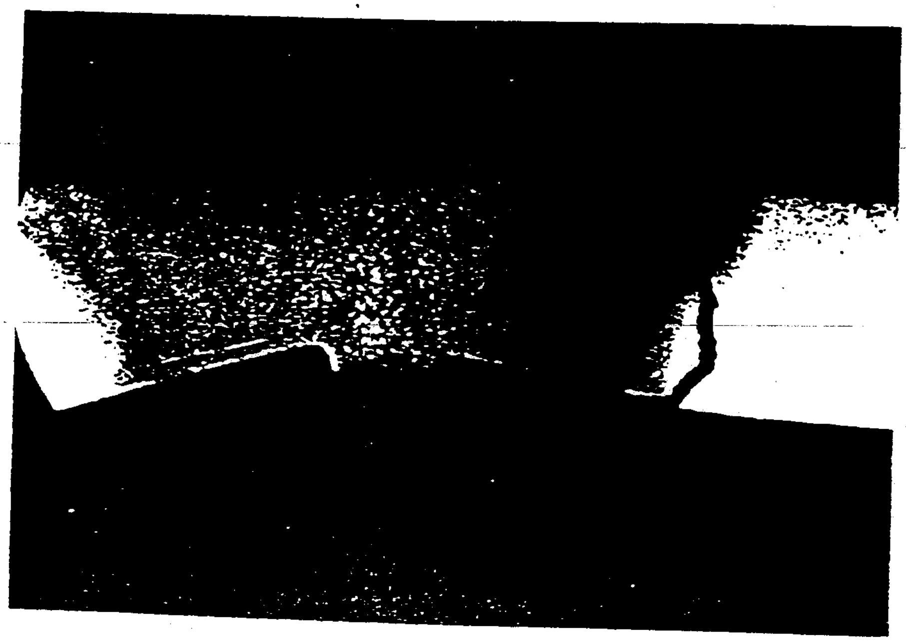


Figure C-8 Hard Spot Crack Initiation From Heat Affected Zone on the Outside Diameter

APPENDIX D

ALERT NOTICES

U.S. Department
of Transportation

Research and
Special Programs
Administration

400 Seventh St., S.W.
Washington, D.C. 20590

JAN 28 1988

TO: ALL NATURAL GAS PIPELINE TRANSMISSION OPERATORS AND ALL HAZARDOUS LIQUID PIPELINE OPERATORS

The purpose of this letter is to advise you of recent findings relative to factors contributing to operational failures of pipelines constructed with Electric Resistance Weld (ERW) pipe manufactured prior to 1970. If you have such pipe in your pipeline system, the Office of Pipeline Safety recommends that you read the enclosed "Alert Notice" and take appropriate preventive steps.

Sincerely,

Richard L. Beam

Richard L. Beam
Director
Office of Pipeline Safety

Enclosure

ALERT NOTICE

The Office of Pipeline Safety (OPS) has data on twelve hazardous liquid pipeline failures that occurred during 1986 and 1987 involving pipe seams manufactured prior to 1970 by the Electric Resistance Weld (ERW) process. The purpose of this notice is to advise pipeline operators who have such pipe in their systems of the data currently available to OPS and of actions which the operator may take to reduce the risk of failure.

These recent failures have caused the OPS to reevaluate the safety of continued operation of all pre-1970 ERW pipelines. This reevaluation has included more definitive metallurgical examinations of failed ERW seams. Of particular significance to the OPS evaluation of ERW pipe is the failure of an 8-inch diameter pipeline in Mounds View, Minnesota. The Mounds View pipeline carrying gasoline which failed at 1434 psig had been hydrostatically pressure tested to 1900 psig just two years prior to this accident. An independent failure analysis conducted by Battelle Columbus Laboratories concluded that the cause of the Mounds View failure was selective corrosion in the ERW seam in an area of inadequate cathodic protection. Similar metallurgical tests have identified at least two other recent failures where selective corrosion of the ERW seam in an area characterized by coating disbondment and inadequate cathodic protection contributed to the cause of the failure.

Studies of available data by the OPS staff have shown that ERW seams have been involved in 145 service failures in both hazardous liquid and natural gas pipelines since 1970, and that of these failures, all but two occurred on pipe manufactured prior to 1970. Although definitive metallurgical examination of the failures, to establish cause, had not been done, selective seam corrosion appears to be a contributing cause of failure in a significant number of these incidents.

Past OPS regulatory and enforcement actions have resulted in hydrostatic testing of some ERW pipelines thus reducing the risk of seam failures. First, when the gas pipeline safety standards (49 CFR Part 192) were initially promulgated by OPS, natural gas operators were required to establish an upper limit on operating pressure for each pipeline. In many cases, the operator had to perform a hydrostatic test in order to qualify the pipeline for the desired pressure. Additionally, in 1980, the OPS promulgated new regulations for highly volatile liquid (HVL) pipelines (49 CFR Part 195) requiring operators of those pipelines to test all HVL pipelines to establish a maximum operating pressure not to exceed 80% of a previous operating or test pressure. Further, state or federal enforcement actions have required certain hazardous liquid pipeline operators to hydrostatic test a number of specific segments of their pipeline systems that had experienced ERW seam failures. Collectively, these actions involved the testing of thousands of miles of gas transmission, highly volatile liquid and other hazardous liquid pipelines. This testing resulted in the removal from service of several hundred joints of pipe having defective seams and provided additional assurance of the integrity of the remaining pipe in the tested pipelines. Pre-1970 ERW pipelines which were hydrotested have, in most cases, operated safely since they were tested.

Therefore, in view of these recent findings, OPS recommends that all operators reevaluate the potential for safety problems on their high pressure pre-1970 ERW pipelines. All operators who have pre-1970 ERW pipe in their systems should carefully review their leak, failure, and test history as well as their corrosion control records to ensure that adequate cathodic protection has been and is now being provided. In areas where cathodic protection has been deficient for a period or periods of time, the operators should conduct an examination of the condition of the pipeline, including close interval pipe-to-soil corrosion surveys, selective visual examination of the pipe coating, and/or other appropriate means of physically determining the effects of the environment on the pipe seam. If an unsatisfactory condition is found, or if a pre-1970 ERW pipeline has not been hydrostatic tested to 125% of the maximum allowable pressure, operators should consider hydrostatic testing to assure the integrity of the pipeline.

U.S. Department
of Transportation

Research and
Special Programs
Administration

400 Seventh Street, S.W.
Washington, D.C. 20590

MAR - 8 1989

TO: ALL NATURAL GAS TRANSMISSION OPERATORS AND ALL HAZARDOUS LIQUID PIPELINE OPERATORS

The purpose of this letter is to advise you of additional findings since the January 28, 1988 "Alert Notice" relative to factors contributing to operational failures of pipelines constructed with Electric Resistance Weld (ERW) pipe manufactured prior to 1970. If you have such pipe in your pipeline system, the Office of Pipeline Safety recommends that you read the enclosed copy of the latest "Alert Notice" and take appropriate preventive steps.

Sincerely,

Richard L. Beam

Richard L. Beam
Director
Office of Pipeline Safety

Enclosure

ALERT NOTICE

On January 28, 1988, the Office of Pipeline Safety (OPS) issued an Alert Notice advising pipeline operators who have pipe manufactured by the Electric Resistance Weld (ERW) process of the occurrence of twelve hazardous liquid pipeline failures and of actions which operators may take to reduce the risks of similar failures.

The continuing failure of ERW seams remains a matter of concern to the Research and Special Programs Administration (RSPA). Since the issuance of that Alert Notice, the RSPA has data on eight additional hazardous liquid pipeline failures and one on a gas transmission pipeline involving pipe seams manufactured prior to 1970 by the ERW process. Of the eight additional hazardous liquid pipeline failures, two appear to be due to selective corrosion of the ERW seam. As stated in the 1988 Alert Notice, seams with selective corrosion occurring in an area of manufacturing defects may be particularly vulnerable to failure. However, the other failures appear to have resulted from flaw growth of manufacturing defects in the ERW seam.

Two of these failures resulted in some of the most significant spills (more than 20,000 bbls.) in recent years. Both of these failures involved pipelines which had not been hydrostatically tested in accordance with current standards. One of the failures occurred after the long-standing operating pressure had been increased a relatively short period of time before the failure. This increase in pressure clearly decreased the margin of safety between the operating pressure and highest pressure ever experienced during the life of the pipeline and contributed to the acceleration of the growth of a defect to failure.

The RSPA is planning to conduct research aimed at characterizing ERW defects and their growth rates for a variety of environmental conditions, in addition to the pipe having cathodic protection at less than standard pipe-to-soil potentials, coating disbondment, fatigue, and corrosion fatigue. If the research is successful, the resulting data could provide a basis for establishing criteria regarding when an ERW pipeline should be rehydrotested.

In view of the continuing ERW seam failures, OPS recommends that all pipeline operators having ERW pipelines installed prior to 1970:

(1) Consider hydrostatic testing all hazardous liquid pipelines that have not been hydrostatically tested to 125 percent of the maximum allowable pressure, or alternatively reduce the operating pressure 20 percent;

(2) Avoid increasing a pipeline's long-standing operating pressure;

(3) Assure the effectiveness of the cathodic protection system. Consider the use of close interval pipe-to-soil surveys after evaluating the pipe coating and corrosion/cathodic protection history; and

(4) In the event of an ERW seam failure, conduct metallurgical examinations in order to determine the probable condition of the remainder of the ERW seams in the pipeline.

APPENDIX E

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